NAVY EXPERIMENTAL DIVING UNIT

TECHNICAL REPORT NO. 10-97

FURTHER EVALUATION OF A LITHIUM BATTERY IN THE MK 16 MOD 0 UNDERWATER BREATHING APPARATUS (UBA)

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The MK 16 Underwater Breathing Apparatus (UBA) is an electronically controlled mixed gas rebreather. To meet projected mission requirements, Naval Special Warfare Command (COMNAVSPECWARCOM) tasked Naval Surface Warfare Center, Crane Division (NSWC) to develop a MK 16 UBA battery pack with a nominal duration of 160 hrs. Subsequently, Naval Sea Systems Command (NAVSEA) tasked Navy Experimental Diving Unit (NEDU) to evaluate the prototype 9 volt lithium batteries developed by NSWC. Testing was conducted at NSWC Crane and the results reported in NEDU Technical Report 4-96. As a result of this report, Program Executive Office, Carriers, Littoral Warfare and Auxiliary Ships (PEO-CLA) PMS-325J submitted a deviation from specification from Explosive Ordnance Disposal Technical Division requesting authorization for Naval Special Warfare to use the new lithium batteries in lieu of the current lead acid batteries.

A review of NEDU Technical Report 4-96 together with additional in-house testing yields the following conclusions:

The lithium battery has a duration of about 120 hrs with a MK 16 UBA in a steady green mode. If the primary display indicates flashing red and green, remaining battery duration is on the order of 6 hrs.

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The secondary display will indicate a one with a decimal point (1.) when battery voltage is above 6.8 v. Once voltage drops below 6.8 v, the secondary display will indicate a three digit reading, e.g., 1.99. Once this reading is displayed, lithium battery voltage can be expected to drop to 5.8 v within about 6 hrs and the primary display will transition from steady green to flashing red and green.

The duration of the lithium battery with the primary display showing steady green is reduced by about 10 hrs when operated at 35° F.

To meet the 160 hr SPECWAR goal, the MK 16 UBA must be placed in a modified standby mode for storage.

Based on 1271 hours of testing, the increased initial voltage of the lithium battery does not appear to have detrimental effects on MK 16 UBA electronics.

Although the manufacturer recommends a shelf life of 10 yrs, NEDU supports Crane's recommendation for a shelf life of 7 yrs.

The lot test plan proposed by NSWC, Crane is based upon MIL-STD-105D (Sampling Procedures and Tables for Inspection by Attributes)8 and should provide acceptable quality assurance.

Based upon our conclusions, NEDU recommends that the lithium battery be approved for use in the MK 16 UBA as requested by PEO-CLA PMS 325J. Battery logs should be maintained for each battery. Those batteries having more than 120 hours of usage should not be used except for training missions.

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BACKGROUND

The MK 16 Underwater Breathing Apparatus (UBA) is an electronically controlled mixed gas rebreather. The control circuits for this UBA are powered by a lead acid, 6 volt battery with a nominal duration of 10 hrs. To meet projected mission requirements, Naval Special Warfare Command (COMNAVSPECWARCOM) tasked Naval Surface Warfare Center, Crane Division (NSWC) to develop a MK 16 UBA battery pack with a nominal duration of 160 hrs[1]. The proposed scenario was that the UBA would be set up and staged for the first 100 hrs, then used for the next 9 hrs at 35° F. The MK 16 would then be cached at -20° F for 48 hrs, then used at 35° F for an additional 2 hrs[2].

Subsequently, Naval Sea Systems Command (NAVSEA) tasked Navy Experimental Diving Unit (NEDU) to evaluate the prototype batteries developed by NSWC[3]. These batteries were 9 volt lithium batteries. Testing was conducted at NSWC Crane and the results reported in NEDU Technical Report 4-96[4]. As a result of this report, Program Executive Office, Carriers, Littoral Warfare and Auxiliary Ships (PEO-CLA) PMS-325J submitted a deviation from specification from Explosive Ordnance Disposal Technical Division requesting authorization for Naval Special Warfare to use the new lithium batteries in lieu of the current lead acid batteries.

At a meeting of the MK 16 UBA Configuration Control Board, a number of questions were raised regarding the NEDU technical report. These questions included:

1) What are the maximum number of battery hours to support Naval Special Warfare (NSW) missions?

2) Does use of the lithium battery affect the secondary display? Specifically:

a. What indications of battery condition are shown on the secondary display when the lithium battery is used vice the lead acid battery?

b. What warning signals will a diver receive if the lithium battery fails?

c. In what manner does the lithium battery fail?

3) What is the effect of increased battery voltage (from 6 v to 9 v) on MK 16 UBA electronics?

4) What is battery shelf life?

5) What is the manufacturing lot size?

NEDU was asked to review report 4-96 and if necessary conduct additional testing in house to clarify any issues[5]. We have completed this review and testing and the results are provided in this report, together with specific technical recommendations.

REVIEW OF NEDU TECHNICAL REPORT 4-96

The original testing was conducted in four series. In support of COMNAVSPECWARCOM requirements, testing generally followed the scenario shown in Table 1.

Table 1. Series #1 Testing

Test Time (Hours:minutes)	Test Temperature °C (°F)
100:00	24 (75)
8:45	2 (35)
48:00	-29 (-20)
Until termination	2 (35)

Series #1 testing was conducted by NSWC Crane using an electronic load bank. A continuous current draw of 11 mA was used to determine battery life. While the eight batteries tested lasted 160 hours, serious questions were raised in the report as to whether or not 11 mA was a realistic current draw.

As a result of the Series #1 testing, NEDU together with NSWC Crane, conducted Series #2 testing. This series used a four phase approach which is shown in Table 2. A total of eight batteries were tested at each of three temperatures; -28.9° C, 1.7° C, and 23° C.

Table 2. Series #2 Testing

Test Hours	Current Draw
8	23.1ma/30.7ma (::45/::15)
142	23.1 mA continuous
8	23.1ma/30.7ma (::45/::15)
Until termination	23.1 mA continuous

The current draws shown were picked based upon conversations with personnel from EOD Tech Div. It was believed that the minimum current draw was 23.1 mA with a

possible maximum draw of 30 mA. Testing was conducted using fixed resistors in a load bank to simulate current draw of an actual MK 16 UBA.

The results of Series #2 testing were questionable, again because of concerns as to the real current draw of an operational MK 16 UBA. Because of this, NEDU embarked upon a third series of testing. This series basically repeated the scenario shown in Table 2. However, in addition to using the electronic load bank, two operational MK 16's were used to characterize the true current draw.

The results of Series #3 testing showed that current draw for a MK 16 in "ready standby" mode was 35.8 mA with a peak draw of 43 mA at the beginning of a run with a fully charged battery. Using a 35.8 mA draw caused all batteries to be depleted in about 110 hrs. For purposes of this testing, depletion was defined as battery voltage dropping to 5.8 v. It is important to note that this 5.8 v cutoff was based on the fact that at that voltage the controlling software will transition the primary display from steady green to alternating red/green.

The probable causes of alternating red/green primary display (when ppO_2 is within normal range) are: (1) defective primary electronics assembly battery, (2) primary electronics assembly out of calibration, and (3) defective primary electronics assembly. In this case, transition is an early warning ("heads up") to the diver that the operating voltage of the primary battery is 5.8 v (.00 secondary display reading). According to the MK 16 UBA Technical Manual (SS600-AH-MMA-010) [6] the MK 16 UBA continues to operate satisfactorily below the normal operating voltage of 5.8, down to approximately 5.2v. The MK 16 UBA oxygen addition valve and primary display will not function reliably when the primary battery falls below 5.2 v. Also, the rechargeable lead acid batteries can be damaged below 5.2 v. This does not apply to lithium batteries since they are not rechargeable.

Current Reduction Procedure

Because of SPECWAR's requirement for the battery to last 160 hrs, we investigated various methods to obtain this duration. In the "ready standby" mode, the primary display for the UBA is steady green. This condition results in the highest current draw. NEDU proposed that current draw could be reduced by modifying the standby mode. If the MK 16 is flushed with air after the initial setup, and the DIVE/SURFACE valve placed in the SURFACE position, the red LED on the primary display flashes on and off. This condition results in an average current draw of 23.6 mA (11.3 to 35.8 mA). This modified standby was used in Series #4 testing, details of which are shown in Table 3.

Table 3. Series #4 Testing

Test Time (Hours:minutes)	Current Draw (mA) (Light on/off)
100:00	35.8/11.3 @ 4 hertz
8:45	35.8 continuous
48:00	35.8/11.3 @ 4 hertz
Until termination	35.8 continuous

Results from Series #4 testing showed that 23 of 24 batteries met or exceeded the 160 hr goal before reaching 5.2 v. The single failure was precipitous in nature suggesting a manufacturer defect. Hence, the 160 hr goal can be met but only by modifying the set up procedure and "standby" mode for the MK 16 UBA.

Series #4 testing also demonstrated problems with storing the MK 16 UBA at -20° F. First, both the oxygen and diluent gas flasks emptied during storage. Second, the voltage of the lithium batteries dropped below 5.2 v. As discussed above, this criteria is really not applicable to the lithium batteries but rather the lead acid rechargeable batteries. Once the batteries were rewarmed, voltage rose and they functioned properly.

One deficiency with the Series #4 testing was that the secondary display was not monitored. Therefore, Technical Report 4-96 did not discuss the type of secondary readings which a diver would expect to see if the lithium battery was used vice the lead acid battery.

TR 4-96 recommended that EOD Technical Division determine the minimum voltage level at which the MK 16 will function reliably. EOD responded by conducting informal testing of the add valve function and the primary battery voltage change.

<u>Review of EODTECHDIV data</u>

Some of the pertinent EODTECHDIV test results are shown in Table 4. Battery voltage was varied from 9 volts to below 3 volts. At the same time, controlled voltages were input to simulate various O_2 sensor readings (99 mv - high O_2, 75 mv - proper O_2, 59 mv - low O_2, 55 mv - very low O_2). The effects of the various combinations of battery voltage and sensor input on primary display readings, add valve functioning and add valve driving voltage were observed. For instance, under nominal conditions, a steady green (SG) primary display means the O_2 level is correct, there is no driving voltage applied to the add valve, and therefore the add valve is shut. At a sensor reading of 99 mv, the primary was blinking green (BG), indicating high PO_2. At a 59 mv sensor voltage, the primary display alternated red and green (ARG), and at a seriously low

reading of 55 mv, the display was blinking red (BR). In both low O_2 cases, the driving voltage to the add valve was 103.5 v, and the add valve was ON.

Table 4. Affects of Primary Battery Voltage Change

Primary Battery VDC	Sensor 1-3 mVDC	Add Valve	Drive VDC (V)	Primary Display
9	75	OFF	0	SG
9	99	OFF	0	BG
9	59	ON	103.5	ARG
9	55	ON	103.5	BR
5.8	75	OFF	0	ARG
5.0	59	ON	90.78	ARG
5.0	55	ON	91.6	BR
4.9	59	ON	88.63	ARG
3.9	55	ON	67.88	BR
3.8	55	ON	65.66	ARG
3.5	59	OFF	0	ARG

At 5.8 volts and 75 mv sensor signal, the primary display shifted from steady green to ARG, indicating a declining battery. At a battery voltage of 5 volts and a sensor reading of 55 mv, the primary read properly (BR) and add valve voltage was 91.6 v. At 4.9 volts and a sensor voltage of 59 mv, the primary display read correctly, and the add valve was ON, as it should have been. However, the add valve driving voltage fell below 90 volts. The implication of this is described below.

At a battery voltage of 3.9 volts and a sensor reading of 55 mv, the primary display still read correctly (BR) and the O_2 add valve was open. Driving voltage was 68 volts. At 3.8 volts, and 55 mv sensor output, the primary display shifted to ARG instead of BR, but the O_2 add valve was still functioning. Only at 3.5 volts did the O_2 add valve not turn on as it should.

It is generally assumed that below 90 volts add valve driving voltage, the O_2 add flow rate will drop off, and probably not in a linear fashion with voltage. Presumably, a drop in O_2 add flow rate would increase the "valve on" time. That in itself would not impair the diver unless there is a rapid increases in metabolic oxygen demand, requiring the rig to make up a lot of oxygen in a short period of time. Detailed information on the relation between drive voltage and add valve flow rate is not available to us at this time.

Taking all of the above into consideration, in the one UBA tested by EODTECHDIV, a battery voltage of 5 v maintained O_2 add valve driving voltage above 90 v, and ensured proper primary display readings. Between 5 volts and 3.9 volts, the primary display and add valve functioned properly, but the O_2 add flow rate may have been reduced. Measurements would need to be made to determine the extent of the flow reduction.

Because of several questions raised by the MK 16 UBA Configuration Control Board regarding Technical Report 4-96 as well as questions regarding the behavior of the secondary display, we embarked on a new series of tests. The results of these tests, described below, will be used to provide specific recommendations to the CCB in support of PEO-CLA PMS 325J request for a deviation from specification.

METHODS

In August 1997, NEDU conducted four separate battery bench tests with the MK 16 UBA:

Bench Test #1. The purpose behind conducting this bench test was to evaluate one 9 v lithium battery and one rechargeable lead-acid 6 v battery. Specifically, the performance of the secondary display using the 9 v lithium battery was compared to the 6 v battery. This included: (1) recording both secondary display readouts and (2) recording the drawdown of the battery voltage using a multimeter. Two MK 16 UBA's were set up per standard pre-dive procedures minus O_2/diluent bottles. Current draw was simulated by inserting one bad O_2 sensor into the MK 16 UBA triggering the electronic system so that the primary display alternated from blinking red to blinking green. At this point of the study, it was believed that the primary display in this configuration would be a sufficient current draw to satisfactorily test the lithium battery in the MK 16 MOD O UBA.

Bench Test #2. The purpose of this bench test was to gain more information on the 9 v lithium batteries. Two batteries and two secondary displays were tested simultaneously. As indicated above , testing included: recording both secondary display readouts and, recording the drawdown of the battery voltage using a multimeter. Two MK 16 UBA's were set up per standard pre-dive procedures with O_2/diluent bottles. Again, current draw was simulated by inserting one bad O_2 sensor into the MK 16 UBA triggering the electronic system so that the primary display alternated from blinking red to blinking green. To simulate a more realistic current draw, the O_2 add valve was activated throughout this test. The activation of the O_2 valve was accomplished by the following procedure: the MK 16 UBA mouthpiece was placed in the dive position. This allowed ambient air to enter the breathing loop of the MK 16 UBA and decrease the percent of oxygen in the breathing mix. The decrease in oxygen caused the O_2 add valve to actuate, thereby increasing the percentage of oxygen in the breathing loop. Since the breathing loop was open to the atmosphere, the O_2 valve was continuously actuating and adding oxygen.

Bench Test #3. The purpose behind conducting this bench test was to evaluate two additional 9 v lithium batteries with the primary display in the solid green configuration which would cause greatest current draw. As in Bench Test #2 we recorded both secondary display readouts and the drawdown of the battery voltage. In addition, we recorded the current draw using a multimeter. Two MK 16 UBA's were set up per standard pre-dive procedures with O_2/diluent bottles.

Bench Test #4. The purpose behind conducting this bench test was to evaluate one 9 v lithium battery in a cold environment while monitoring the performance of the secondary display. As in Bench Test #3, we recorded the secondary display readout, the drawdown of the battery voltage and the current draw using a multimeter. The MK 16 UBA was set up per standard pre-dive procedures with O_2/diluent bottles. The primary display was solid green at the start of the dive. The MK 16 was placed in a temperature regulated container (the secondary display remained outside the container). Temperature was regulated between 30° to 35° F.

Table 5 shows the difference between the four bench tests.

Table 5. Matrix of Test Differences

					Interventions		Result
Bench Test	Record Secondary Display	Record Voltage	O_2/Diluent Bottles	Temp	Bad O_2 Sensor	O^2 Add Valve	Primary Display
#1 (9 v/6 v)	X	X		Ambient	X		Alt red/green
#2 (9 v/9 v)	X	X	X	Ambient	X	X	Alt red/green
#3 (9 v/9 v)	X	X	X	Ambient			Steady green
#4 (9v)	X	X		30-35° F			Steady green

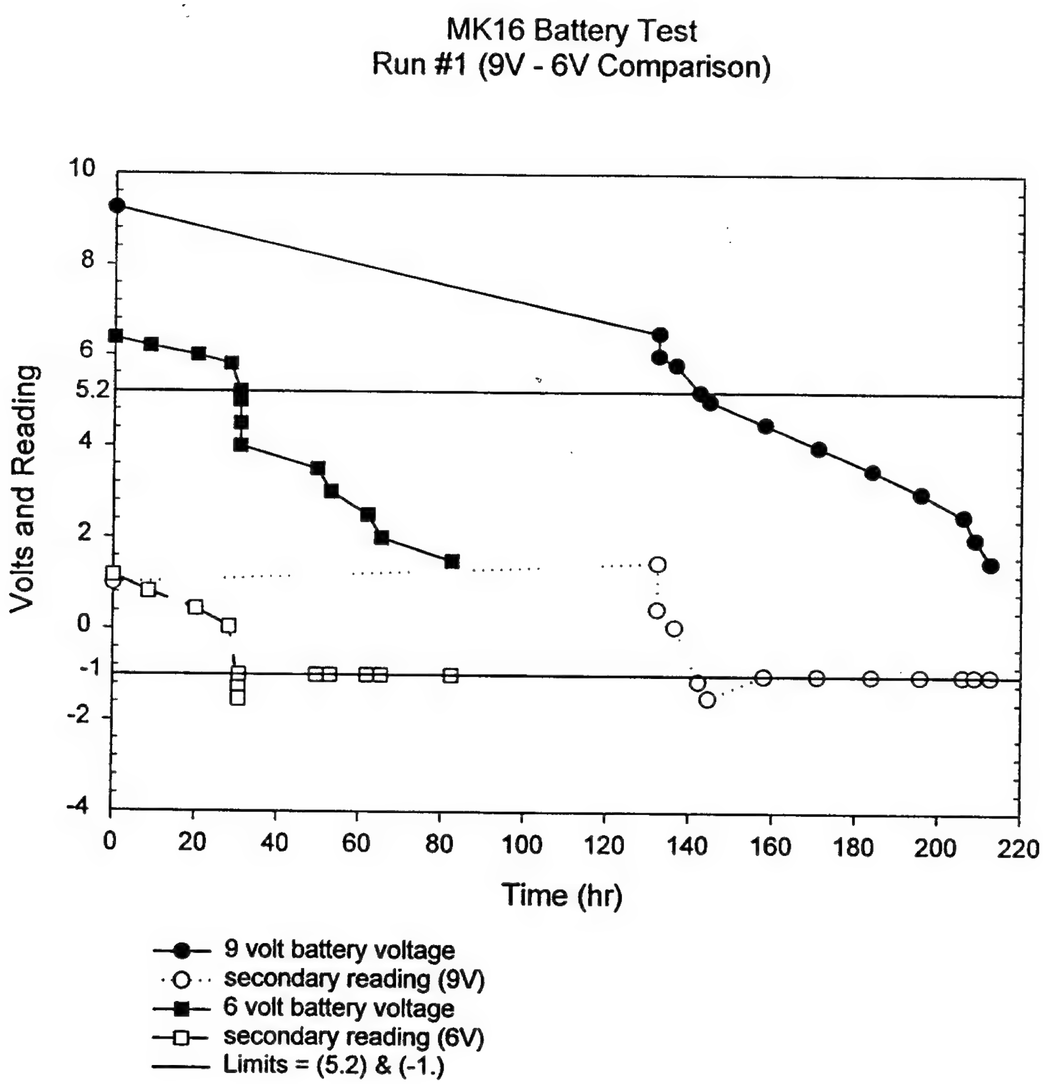
RESULTS

The normal operating display range of the secondary display is from 1.99 (6.8 v) down to -1.99 (4.7 v). Above 6.8 v, the secondary display yields a (1.) and below 4.7 v, the secondary display yields a (-1.).

Bench Test #1. Secondary display reading indicated the single digit one (1.) above 6.8 v with the 9 v lithium battery. As voltage decreased, the 9 v lithium battery and the rechargeable lead-acid 6 v batteries yielded similar secondary display readings. At 5.8 v

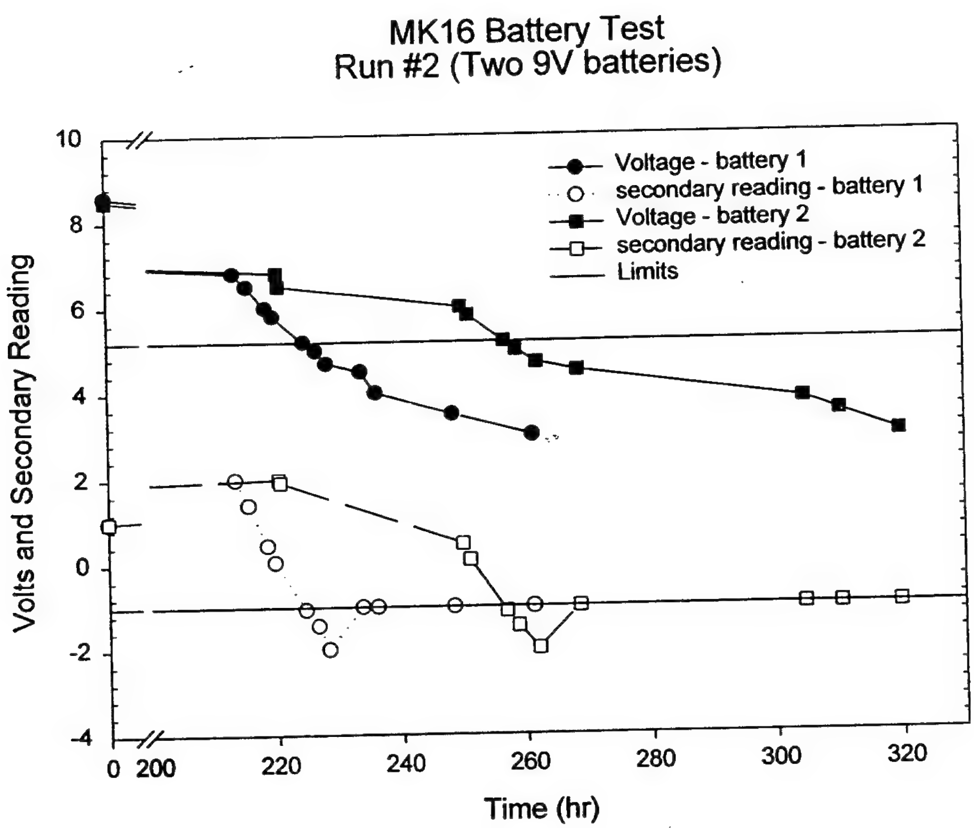
the 9 v lithium battery secondary display readout was 0.06 (137 hrs) and the 6 v rechargeable lead acid secondary display readout was 0.05 (28 hrs). Below 4.7 v with both batteries, the secondary display readings indicated the single digit minus one (-1.). For data collection purposes we depleted the 9 v lithium battery down to 1.5 v. The 9 v lithium battery reached 1.5 v after 212 hrs while the lead-acid battery reached 1.5 v after 82 hrs. Results are shown in Figure 1.

Figure 1



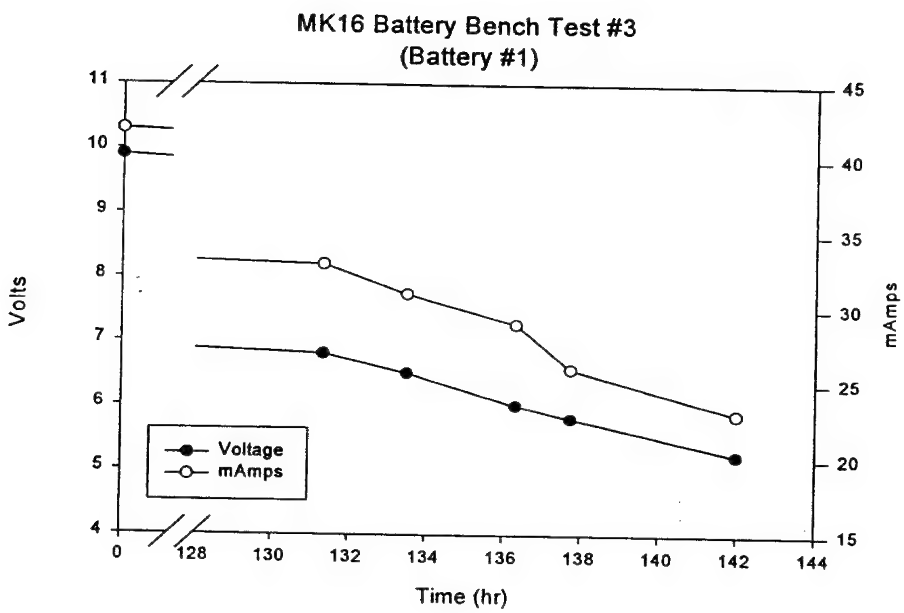
Bench Test #2. Secondary display readouts were similar to the 9 v lithium results from Bench Test #1. At 5.8 v, the battery #1 secondary display readout was 0.06 (220 hrs) and battery #2 secondary display readout was 0.09 (251 hrs). For data collection purposes the 9 v lithium battery #1 reached 3 v after 261 hrs while the 9 v lithium battery #2 reached 3 v after 319 hrs of operation. These results are shown in Figure 2.

Figure 2



Bench Test #3. Secondary display readouts were similar to the 9 v lithium results from Bench Test #2. The significance of this test is the measure of current draw and the fact that at 5.8 v the primary display transitioned from steady green to a flashing red/green. At 9 v battery #1 current draw readout was 42mA and battery #2 current draw readout was 39mA. At 5.8 v, battery #1 current draw was 26mA and the secondary display readout was -0.13 (138 hrs). At 5.8 v, battery #2 current draw was 24 mA and the secondary display readout was -0.09 (124 hrs). These results are shown in Figures 3 and 4.

Figure 3


MK16 Battery Bench Test #3
(Battery #1)
Volts
mAmps
Voltage
mAmps
Time (hr)

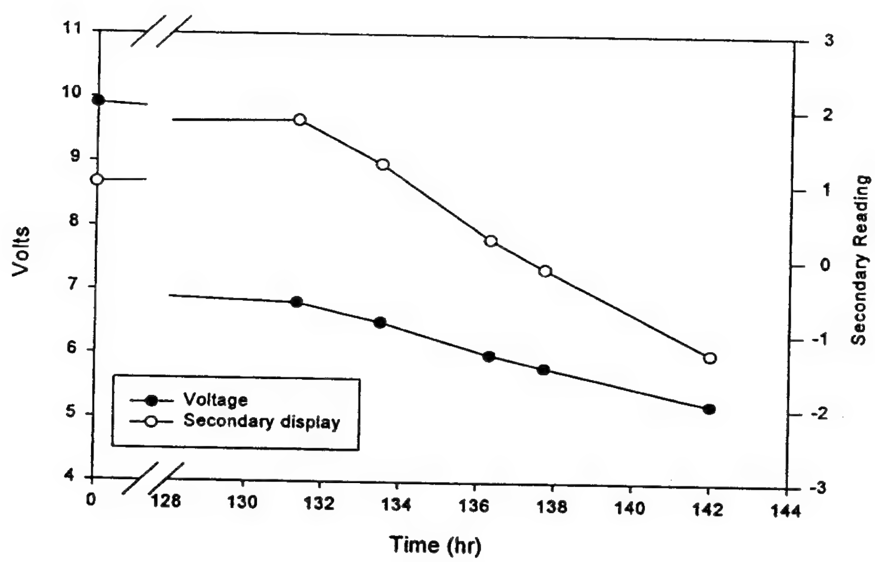
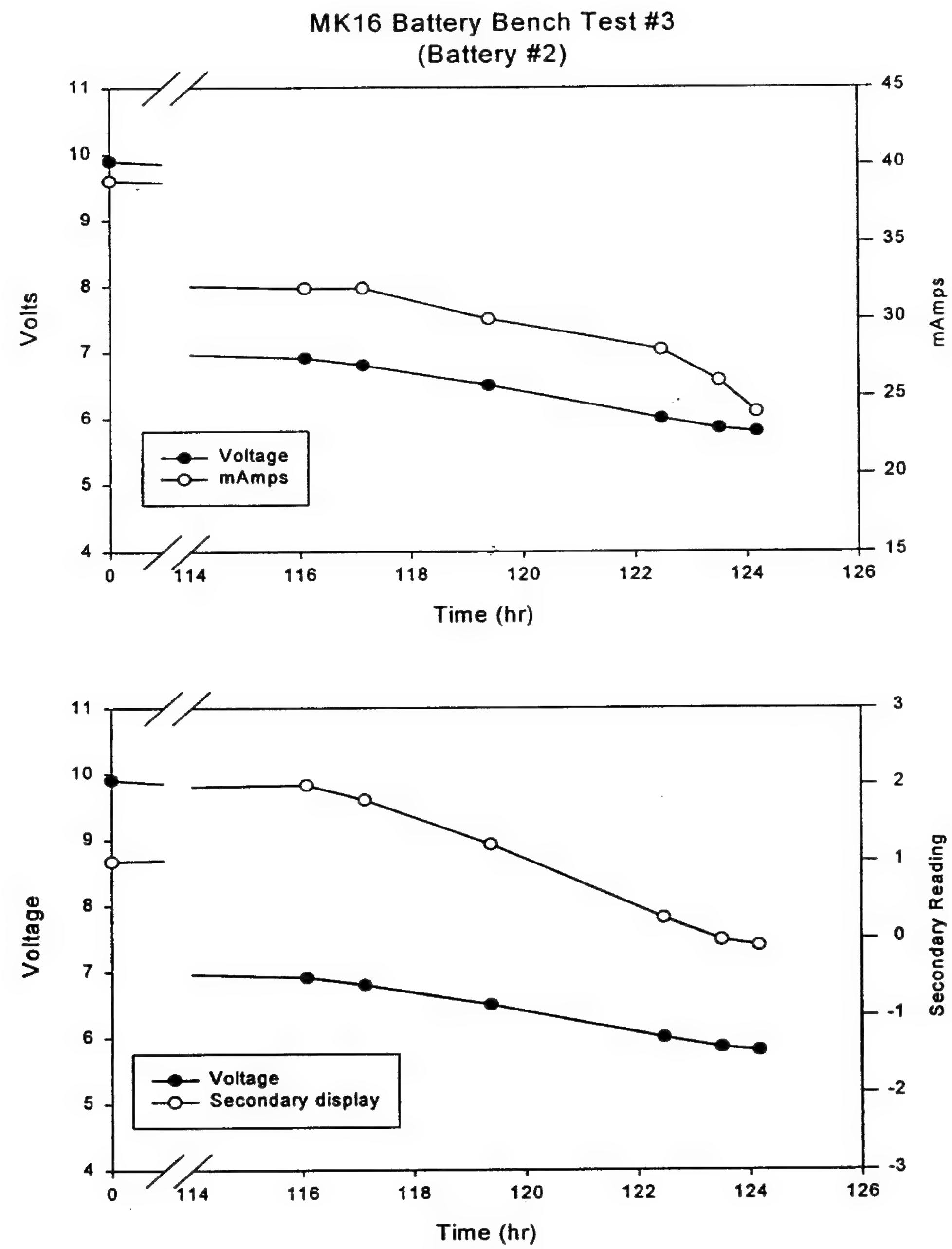

Volts
Secondary Reading
Voltage
Secondary display
Time (hr)

Figure 4


MK16 Battery Bench Test #3
(Battery #2)
Volts
mAmps
Voltage
mAmps
Time (hr)
Voltage
Secondary Reading
Voltage
Secondary display
Time (hr)

Bench Test #4. Secondary display readout was similar to the 9 v lithium results from Bench Test #3. The significance of this test was the effect of temperature on the primary lithium battery. At 8.6 v, current draw was 42mA. At 5.8 v current draw was 28mA and the secondary display readout was 0.01 (121 hrs). For data collection purposes the 9 v lithium battery duration was 129 hrs at 4.73 v (20 mA). These results are shown in Figure 5.

DISCUSSION

As requested by the MK 16 UBA configuration control Board, NEDU conducted additional in-house testing to clarify a number of issues raised by NEDU Technical Report 4-96. These issues are discussed below. For comparative purposes, a cut off voltage of 5.8 v was used since at this voltage the primary display transitions from steady green to alternating red and green.

Secondary Display: Testing was conducted to determine:

1. What indications of battery condition are shown on the secondary display when the lithium battery is used vice the lead acid battery?

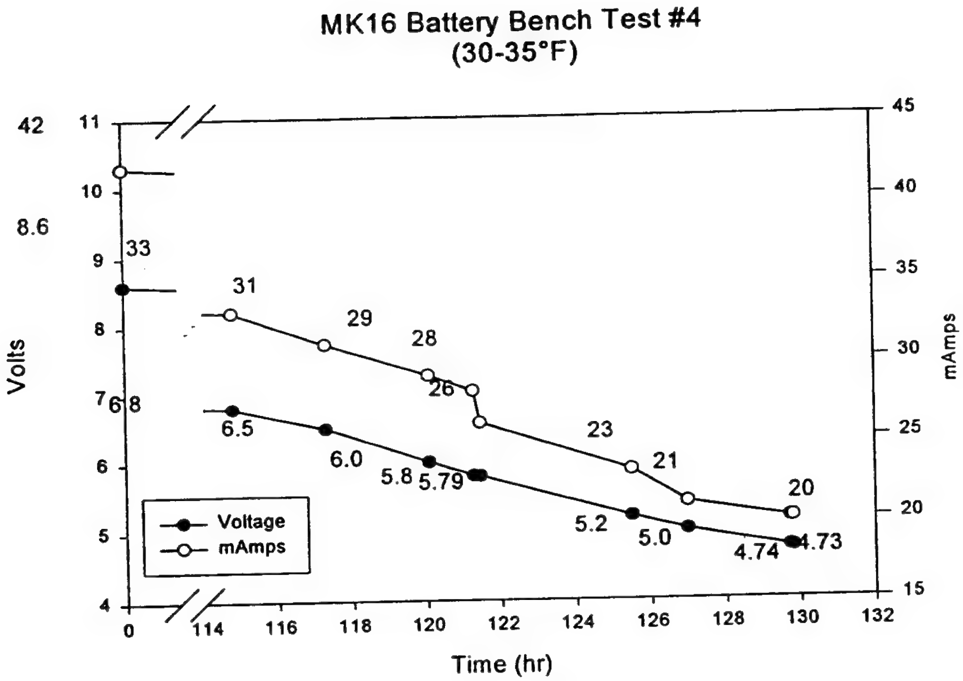
2. What warning signals will a diver have if the lithium battery fails?

3. How does the lithium battery fail?

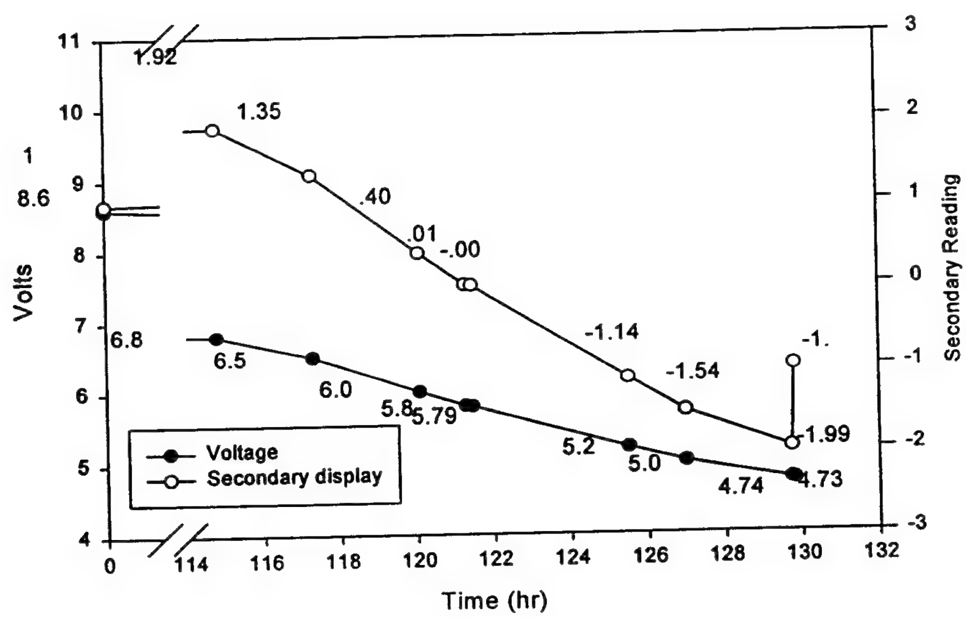
4. Will the secondary battery support the demands of the primary lithium battery?

Results of our testing showed that between 9.25 and 6.8 v, the secondary display readings indicates a single digit one (1.) with a decimal point. Once lithium battery voltage drops to 6.8 v, the secondary display will indicate a reading of 1.99. As battery voltage decreases further, secondary readings are virtually identical to those seen with the current lead acid battery. Once the voltage drops below about 5.8 v, the secondary display indicates a negative number for battery condition. For example, at a battery voltage of 5.3 v, the secondary displays a -1.00. At 4.7 v, the secondary display shows -1.99. Once voltage drops below 4.7 v, the secondary display shows a negative one with a decimal point (-1.).

Figure 5



MK16 Battery Bench Test #4
(30-35°F)
Volts
mAmps
Time (hr)
Voltage
mAmps
42
8.6
33
31
29
28
26
23
21
20
6.8
6.5
6.0
5.8
5.79
5.2
5.0
4.74
4.73



Volts
Secondary Reading
Time (hr)
Voltage
Secondary display
1.92
1.35
.40
.01
-.00
-1.14
-1.54
-1.
-1.99
1
8.6
6.8
6.5
6.0
5.8
5.79
5.2
5.0
4.74
4.73

Under current operating guidelines, a MK 16 diver terminates his dive when the secondary display gives a negative number for battery condition. This condition is met at the same voltage (approximately 5.8 v) whether the lead acid or lithium battery is used for the primary electronics. This is due to the nature of the controlling software. In several of our tests, we operated the MK 16 UBA with the lithium battery until voltage dropped below the 5.8 v level required for UBA operation. The battery does not fail suddenly but rather gives the diver ample warning through the secondary display.

The secondary display assembly utilizes a liquid crystal display (LCD) to provide quantitative information to the diver on the condition of the breathing medium, the primary battery voltage, and condition of the secondary batteries. The secondary display is powered by four 1.5 v carbon zinc batteries to support the 6 v lead acid rechargeable battery. NEDU conducted a bench test involving the 1.5 volt alkaline secondary display batteries. The purpose of the test was to record the duration of both types of secondary batteries in support of the 9 v lithium battery. The MK 16 UBA was set up per standard pre-dive procedures with O_2/diluent bottles. The primary display was solid green at the start of the dive. The red and green light emitting diode (LED) contained within the primary display housing was disconnected to conserve primary battery voltage. The MK 16 UBA was placed in a temperature regulated container with the secondary display remaining inside the container. Temperature was regulated between 36° to 39° F. The primary lithium battery yielded over 400 hours in this configuration and four 1.5 v alkaline secondary batteries are still in operation after 32 days. The 1.5 v carbon zinc secondary batteries will be tested in the same MK 16 UBA configuration following the demise of the 1.5 v alkaline batteries.

<u>**Effects of Lithium Battery on MK 16 UBA Electronics**</u>: The MK 16 UBA CCB questioned whether or not use of the lithium battery with its higher initial operating voltage, might cause damage to the MK 16 electronics. During our testing, which totaled 1271 hrs using two different MK 16's, there were no failures of the electronic systems, including the O_2 piezoelectric valves. Additionally, previous testing conducted at NSWC, Crane, did not result in any MK 16 failures. Total duration of testing at Crane was on the order of 390 hrs.

<u>**Effects of Reduced Ambient Temperature**</u>: Reduction in ambient temperature to 35° F resulted in a slight decrease in lithium battery duration (on the order of 10 hrs) with a cut off voltage of 5.8 v. In our tests, battery duration was about 120 hrs at 39° F with a steady green primary display (current draw 40 mA). This is consistent with the manufacturer's technical data supplied by NSWC, Crane which predicts a battery capacity of 121 hrs at 40 mA at 32° F.

<u>**Battery Duration**</u>: The results of our testing are summarized in Table 6. Again, battery duration is referenced to a standardized cut off voltage of 5.8 v.

Table 6. Summary of Battery Durations

Test Number	Condition	Cut Off Voltage	Current Draw	Duration
1 9 v/6 v	Flashing Red/Green Ambient Temp	5.8 v	Not Measured	9 v - 137 hrs 6 v - 28 hrs
2 9 v/9 v	Flashing Red/Green O_2 Solenoid Activated Ambient Temp	5.8 v	Not Measured	Batt #1 - 220 hrs Batt #2 - 251 hrs
3 9 v/9 v	Steady Green Ambient Temp	5.8 v	Batt #1: Start 42 mA Stop 26 mA Batt #2: Start 39 mA Stop 24 mA	138 hrs 124 hrs
4 9 v	Steady Green 35° F	5.8 v	Start 42 mA Stop 28 mA	121 hrs

The most common mode of operation of the MK 16 UBA is with the primary display showing a steady green. In this case, current draw is on the order of 38 to 40 mA and a duration of 120 hrs can be expected. For the most part, this is consistent with Series #3 testing reported previously[5]. If the MK 16 UBA is stored in a mode where the primary display shows flashing red and green, much longer battery durations will be achieved; on the order of 160 hours.

We can speculate that the power savings accruing from the flashing red primary display is due to the flashing condition and not to the color of the LED. Consequently, a flashing green light may result in the same power savings as the flashing red. If the flashing green is preferred for engineering reasons related to the reliability of the O_2 add valve, then an alternative storage condition might be with a high PO_2 resulting in the flashing green condition. We have not tested that and therefore this remains speculation. For this method to be effective, it would also be required that the UBA be stored in a tightly sealed condition, such that the O_2 remains elevated for the duration of the storage.

An unfortunate draw back of the lithium battery is that voltage measurements of the cell prior to installation do not reflect remaining battery life. With the current lead acid battery, cell voltage of the non-installed cell is a direct indication of remaining life. With the lithium battery, the open circuit cell voltage will always read about 9 v until actual capacity is almost gone. Therefore, the only way to know remaining capacity of the lithium battery is through the use of a battery log or noting the battery indication

readings on the secondary display. However, as discussed above, the secondary reading is "1." until voltage drops below 6.8 v; approximately 115 hrs with a steady green primary display. Once the secondary reading is about 1.99 (6.8 v), the primary display will transition to flashing red and green at 5.8 v in approximately six hrs.

We had three lithium batteries tested under similar conditions in test #1 and #2. They reached a 5.8 v level after the following times: 137 hrs, 220 hrs, and 251 hrs. We have no explanation for this variation other than individual differences in the manufacturing, age of the cells, or minor differences in UBA current draw.

Lithium Battery Safety: NSWC Crane conducted short circuit, high temperature and constant current discharge tests on 9 lithium batteries (3 per test). Based on a safety data package submitted to Naval Ordnance Center, the lithium battery was granted a Safety Certification[7].

Lot Testing: A detailed testing scheme proposed by Crane is presented in Appendix A and will only be summarized here. Using Level II testing[8], 50 batteries from a 500 battery lot should be tested with no more than 3 failures. Once a lot has zero failures, Level I testing can be instituted. Level I requires 20 batteries from a 500 battery lot be tested, but only allows one failure. These requirements translate into a sample size of 10% under Level II testing and 4% under Level I testing. Failure rates are designed to yield an Acceptable Quality Level (AQL) of 2.5 failures per 100 batteries. If the AQL is exceeded, the lot is considered unacceptable. In general, testing should include open circuit voltage, closed circuit voltage, capacity discharge testing, and visual inspection.

Shelf Life: Ultralife Batteries, manufacturer of the lithium battery, recommends a shelf life of 10 yrs. However, this shelf life is affected by storage temperature. As discussed in Appendix A, lithium batteries can be expected to lose about 3% capacity per year when stored at ambient to cool (22° C) temperatures. Based on this capacity loss, Crane recommends a shelf life of 7 yrs, which equates to a loss of 21% of initial capacity. As discussed in Appendix A, NSWC Crane recommends that an additional ten cells be procured for each lot and subjected to testing in order to better define shelf life.

Battery Drawings: Battery drawings were supplied by Coastal Systems Station Dahlgren Division, Naval Surface Warfare Center (NAVSURFWARCEN COASTSYSTA) and are contained in Appendix B.

CONCLUSIONS

A review of NEDU Technical Report 4-96 together with additional in-house testing yields the following conclusions:

1. The lithium battery has a duration of about 120 hrs with a MK 16 UBA in a steady green mode. If the primary display indicates flashing red and green, remaining battery duration is on the order of 6 hrs.

2. The secondary display will indicate a one with a decimal point (1.) when battery voltage is above 6.8 v. Once voltage drops below 6.8 v, the secondary display will indicate a three digit reading, e.g., 1.99. Once this reading is displayed, lithium battery voltage can be expected to drop to 5.8 v within about 6 hrs and the primary display will transition from steady green to flashing red and green.

3. Once lithium battery voltage drops to about 5.8 v, the primary display will shift from steady green to flashing red and green. Voltage will decrease from 5.8 to 5.2 v in about 4 to 6 hrs depending on the water temperature.

4. The duration of the lithium battery with the primary display showing steady green is reduced by about 10 hrs when operated at 35° F. This is consistent with the manufacturer's technical data.

5. To meet the 160 hr SPECWAR goal, the MK 16 UBA must be placed in a modified standby mode for storage. This modified mode calls for the UBA to be purged with air and the DIVE/SURFACE valve placed in the SURFACE position after initial set up has been completed. As reported previously in NEDU TR 4-96, 23 of 24 batteries exceeded the 160 hr duration in this mode.

6. Based on 1271 hours of testing, the increased initial voltage of the lithium battery does not appear to have detrimental effects on MK 16 UBA electronics. However, if the lithium battery is approved for use, operational forces should monitor electronics failures for any indication that the lithium battery may be the cause.

7. Although the manufacturer recommends a shelf life of 10 yrs, NEDU supports Crane's recommendation for a shelf life of 7 yrs which is more conservative.

8. The lot test plan proposed by NSWC, Crane is based upon MIL-STD-105D (Sampling Procedures and Tables for Inspection by Attributes)[8] and should provide acceptable quality assurance.

RECOMMENDATIONS

Based upon our conclusions, NEDU recommends that the lithium battery be approved for use in the MK 16 UBA as requested by PEO-CLA PMS 325J with the following caveats:

1. Battery logs should be maintained for each battery.

2. Batteries having more than 120 hrs of usage should not be used except for training missions.

3. If the secondary display indicates 1.99 or less, the battery should not be used for operational missions but may be used for training missions. Once a secondary reading of 1.99 is reached, batteries will last another 6 hrs, approximately, at which point the primary display will transition from steady green to alternating red and green.

4. Lots should be tested per recommendations of NSWC, Crane. Initial testing should be accomplished on 50 batteries of a 500 battery lot with only 3 failures allowed. Once a zero failure lot is obtained, testing can be reduced to 20 batteries out of a 500 battery lot. Testing should include open circuit testing, closed circuit voltage, capacity discharge testing, and visual inspection.

5. The initial shelf life of the lithium batteries should be limited to 7 yrs. Testing of stored batteries should be accomplished each year to more accurately determine shelf life. Testing should include open circuit testing, closed circuit voltage, capacity discharge testing, and visual inspection.

REFERENCES

1. Crane Division, Naval Surface Warfare Center, *Test Plan for MK 16 MOD 0 Underwater Breathing Apparatus*, NSWC 6096-TPL-082, (undated).

2. Naval Special Warfare Group One letter 3000 Ser N3/0550 of 5 May 1993, *MK 16 Underwater Breathing Apparatus Battery Improvement Test Plan Review and Concurrence.*

3. Naval Sea Systems Command, Task Assignment 93-018, *Evaluation of Prototype Lithium Battery for the UBA MK 16 MOD 0*, 2 Dec 92.

4. D. Cowgill, *Evaluation of Prototype Lithium Battery for the MK 16 Underwater Breathing Apparatus (UBA)*, NEDU TR 4-96, Navy Experimental Diving Unit, March 1996.

5. Program Executive Office Mine Warfare letter 10560 Ser EOD-22/80 of 11 Sep 97, *Deviation Request for Use of a Lithium Battery in the MK 16 MOD 0 Underwater Breathing Apparatus.*

6. Program Executive Office Mine Warfare, Department of the Navy, Technical Manual Underwater Breathing Apparatus MK 16 MOD O, 16 December 1996 Revision No. 2.

7. Naval Ordnance Center letter 8020 Ser N71/261 of 17 Apr 97, *Lithium Battery Safety Approval for the MK-16 Underwater Breathing Apparatus.*

8. MIL-STD-105D, *Sampling Procedures and Tables for Inspection by Attributes*,8pp 1-9, 41, 45.

APPENDIX A

Crane Division
Naval Surface Warfare Center
Power Systems Department
Rechargeable Power Systems Branch
Crane, Indiana 47522

FINDINGS AND RECOMMENDATIONS FOR THE Mk16 UBA LITHIUM MANGANESE DIOXIDE BATTERY

Date Original Prepared: Thursday, September 18, 1997
Date Latest Revision __: ________

Thursday, September 18, 1997

The following information is provided in response questions posed by the Configuration Control Board regarding the certification of the Mk 16 Underwater Breathing Apparatus (UBA) lithium battery. The points to be addressed are:

- **A) The estimated capacity of the lithium battery under a system load of 40 mA;**
- **B) Documentation of UBA operation without failure using the lithium battery at NSWC Crane;**
- **C) Documentation and recommendation of the battery's shelf/storage life;**
- **D) Results of testing performed at NSWC Crane;**
- **E) Recommended performance and shelf life testing and vendor cell tests; and**
- **F) NSWC conclusions and recommendations.**

A) The estimated capacity of the battery.

1. Manufacturers rated capacity (calculated for a four cell configuration to a 5 Vdc cutoff):

	LOAD	TEMP	TIME
Versus temperature:	@ 25 mA	22 C	184 hrs
		0 C	180 hrs
		-20 C	200 hrs
		-40 C	92 hrs
Calculated for Mk 16	@ 40 mA	22 C	124 hrs
		0 C	121 hrs
		-20 C	135 hrs
		-40 C	62 hrs

Versus load:	120 mA	32 hrs (96 hrs calculated for 40 mA load)
	80 mA	54 hrs (108 hrs calculated for 40 mA load)
	27 mA	184 hrs(124 hrs calculated for 40 mA load)

The average of calculated Mk 16 battery capacities at 40 mA is 109 hrs based on the above information for a fresh battery under a continuous load of 40 mA at ambient temperature .

2. Capacity results from the testing of the battery at NSWC Crane:

Eight batteries were tested at NSWC to determine the capacity while being cycled at 25 mA. The temperature was cycled at 22 C for 99 hrs, 2 C for 9 hrs, -26 C for 41 hrs, and 2 C for 49 hrs. The capacity at 25 mA to 5.0 and 4.3 Vdc is presented on the left while the calculated capacity to 4.3 Vdc at 40 mA is presented on the right in the following table.

25 mA to 5.0 Vdc	25 mA to 4.3 Vdc	40 mA to 4.3 Vdc (calculated)
142 hrs	151 hrs	95 hrs
138 hrs	146 hrs	92 hrs
142 hrs	150 hrs	94 hrs
140 hrs	149 hrs	93 hrs
142 hrs	151 hrs	95 hrs
141 hrs	150 hrs	94 hrs
134 hrs	143 hrs	90 hrs
142 hrs	151 hrs	95 hrs

Based on the load of the actual Mk 16 (variable load between 10 and 40 mA and not a constant 40 mA) the predicted capacity for this temperature cycling scheme is between 110 and 130 hrs.

3. Capacity conclusions and recommendations.

The calculated life of 109 hrs for a continuous 40 mA load at ambient temperature to 5 Vdc and the average calculated life of 94 hours during a continuous 40 mA load during temperature cycling is based on the above information. It is evident that temperature below –20 C has drastic impacts on battery capacity (decreasing it by as much as half at –40 C). It is also known that the Mk 16 UBA does not operate on a constant current of 40 mA but in reality, a variable load between 10 and 40 mA. Based on all the data available it is concluded by NSWC that the life of the battery is between the range of 105 and 130 hrs depending on extreme cold operation. It is recommended that the system be stored above –20 C while the battery is installed and under load in the UBA.

B. Documentation of UBA operation using the lithium battery at NSWC Crane without failure.

At NSWC the battery performance has been demonstrated in two Mk 16 UBA's. Although the UBA was designed to operate using a lead acid battery with a much lower voltage, there have been no anomalies to either the battery or the UBA electronics. The total time of operation using the lithium battery in the Mk 16 at NSWC is documented at 392 hours without failure. Successful and non-detrimental operation has also been documented in several Mk16 units over the life of each lithium battery at the Naval Experimental Diving Unit (NEDU) at Panama City, Florida. NEDU also verified that the primary and secondary display operation remains a valid tool, providing adequate warning for the operator.

C. The shelf life of the battery.

1. The manufacturers rated shelf life.

Ultralife Batteries Inc. state in product specifications that the cells which make up the Mk 16 battery "has a shelf life of up to 10 years." **See the attached cell specification sheets.**

2. Self discharge characteristics.

The charge retention capabilities of a battery chemistry are directly related to storage temperature. For lithium manganese dioxide batteries a self discharge rate of approximately 3% capacity loss per year at ambient temperature is documented. For a more extensive plot of temperature vs. charge retention, refer to the attached reference page.

3. Shelf life conclusions and recommendations.

Untralife Batteries Inc. recommends that the batteries be stored at ambient to cool (22 C) temperatures. The publicized self discharge rate of 3% per year necessitates an approximate 7 year shelf life. At this point the batteries will theoretically have lost 21% of the initial capacity. Actual testing of stored assets will provide essential data to characterize the actual self discharge rates and usable life of the Mk 16 battery.

D. Results of testing performed at NSWC Crane.

1. Temperature cycling for a fixed time and temperature profile

12/6/93 Four test samples were temperature cycled at a continuous 11mA load for a total of 243 hours. The samples were cycled at 71 F for 97

hours, 36.1 F for 9 hours, 71 F for 13 hours, 19.5 F for 48 hours, and 38 F for 76 hours. All four samples delivered 2.8 Ah over the test duration of 243 hours.

2. **Safety testing according to NAVSEA TM S9310-AQ-SAF-010**

10/4/93 Short circuit, high temperature, and constant current discharge into reversal tests were performed on a total of 9 samples (3 for each test). A safety data package was prepared and submitted with updated design features to the Naval Ordnance center Indian Head Md. (N713). The battery was granted NAVSEA safety certification via letter 8020 Ser N71/261, 17 April 97.

3. **Testing of two Mk 16 UBA's**

10/18/95 Two Mk 16 UBA's were tested at NSWC. The tests proved that the battery will operate the unit at lower than 5.2 Vdc. A base power failure occurred during testing which stopped the test prematurely. Both batteries performed the requirements of the test and one battery was still running the rig at 3.5 Vdc at –20 F. The current drain of the Mk 16 was also monitored and found to be a maximum of 40 mA and a minimum of 10 mA. One of the two rigs was set to flash red and green on the display and the other displayed only green. The current of one rig remained between 10 and 30 mA while the other was a constant 40 mA load. The capacities to 4.5 Vdc were 150+ hrs for the 10-30 mA load and 110 hrs for the constant 40 mA load.

4. **Testing of 24 batteries for performance at temperature.**

10/18/95 Twenty four batteries were tested using an alternating 13 to 36mA load while the temperature was cycled from 75 F for 100 hours, to 35 F for 9 hrs, to –20 F for 50 hrs and finally to 35 F for 40 hrs. All batteries passed the requirements except one which dropped unexplainably to 0 Vdc after approximately 105 hrs. The sudden failure of the one battery suggests that a mechanical failure of the connector or intercell wiring occurred. This test provides evidence that actual usage capacities in the UBA may be much higher than calculated.

5. **Capacity tests of 8 batteries at 25 mA during temperature cycling**

6/29/95 This test is explained in paragraph A2 above.

E. Recommended performance and shelf life testing and vendor cell tests.

1. Sample size and test plan according to lot size.

a.) 2000 cells were recently purchased. With this in mind, these figures are based on an initial lot of 500 batteries. According to Military Standard Sampling Procedures and Tables for Inspection, MIL-STD-105D, there are three general inspection levels: I, II, and III. Level I is the least stringent and Level III is the most stringent. The MIL-STD recommends Level II inspection criteria be incorporated unless otherwise directed. It is recommended that Level II requirements be adhered to until the previous lot has zero test failures. If/When there are zero failures in the previous lot it is recommended that sample requirements are reduced to Level I.

b.) Level II requirements state that a sample of 50 batteries should be tested for lot sizes from 281-500 batteries. To maintain an Acceptable Quality Level (AQL) of 2.5 failures per 100 batteries no more than 3 samples may fail testing at Level II. Level I requirements decrease the sample size to 20 but no more than one battery may fail testing to maintain an AQL of 2.5.

c.) The above recommended requirements translate to an approximate sample size of 10% for the initial lot and 5% for all lots succeeding "zero failure" lots.

d.) If the recommended AQL is exceeded or a lot is determined unsatisfactory the entire lot will be screened for material workmanship and/or new cells shall be procured and a new lot manufactured. In either case samples shall be resubmitted for testing and must be determined to have the required AQL prior to issue.

2. Manufacturer testing at the cell level.

Upon manufacturer of the cells the Ultralife Batteries Inc. randomly selects 100 cells from each days production of 2000-4000 cells. They perform the following tests on groups from their sample of 100 cells:

a) Storage tests each quarter consisting of open circuit voltage, closed circuit voltage and impedance testing.

b) Discharge testing at 27 mA (300 Ohms) and 120 mA (60 ohms) resistive loads measuring hours of discharge. They average 45 hours operation at 27 mA. Failure of the lot is indicated by a discharge time of less than 6.7 hrs and 40 hours respectively. Note: Calculation of

capacity using this information suggests that the batteries will last approximately 123 hours at 38 mA ambient temperature which is within the previously calculated capacity.

c) Short circuit testing using a resistance less than 0.1 Ohm. This test is used internally for vendor documentation. It is not used for pass/fail of the production lot.

d) Short circuit testing at 60 C. Leakage may occur only around the peripheral weld area. Distortion of the case is permitted. No fires are allowed. This test is used internally for vendor documentation. It is not used for pass/fail of the production lot.

e) Series forced discharge using two batteries shorted to each other at 18 Vdc.

f) Drop test from approximately 40 inches followed by capacity discharge.

g) High temperature storage at 71 C for 3 weeks and 45 C for 4 weeks followed by discharge. Leaking/rupture of any cell fails the production lot.

h) Temperature and humidity testing at 55 C and 95 Rh for 3 weeks followed by discharge.

3. Recommended testing of batteries at NSWC.

a) A capacity discharge at 40 mA to 4.2 Vdc at ambient temperature of all test samples should be performed. A failure of this test is considered a major failure and will affect the acceptance of the entire lot. It is recommended that a battery capacity less than 4.0 Ah is considered a failure.

b) Voltage under load at 40 mA for 10 seconds of all batteries built prior to issue (included in battery cost). A loaded voltage of less than 9.0 Vdc shall constitute a battery failure. A failure of this test is considered a major failure and will affect the acceptance of the entire lot.

c) Open circuit voltage of all batteries after built prior to storage (included in battery cost). An open circuit voltage of less than 9.2 Vdc shall constitute a failure. A failure of this test is considered a major failure and will affect the acceptance of the entire lot.

d) Open circuit voltage of all cells prior to assembly. Any cell with an open circuit voltage less than 9.2 Vdc shall be considered unusable.

d) Visual inspection of all batteries compared to design drawings (included in battery cost). Anomalies shall be corrected for all batteries within the lot. This inspection shall not affect the acceptance of the lot.

e) Shelf/storage life testing on each produced lot of batteries. Ten additional cells manufactured (in addition to reliability test samples) and stored then capacity discharged in one year increments to determine storage life. The tests from a, b, c, and d above shall be performed. The failure criteria of the above tests will remain pertinent. Storage life tests shall not affect the acceptance of a lot but shall assist in the determination of the shelf life.

F) NSWC conclusions and recommendations.

1. The calculated capacity of the Mk 16 battery is approximately 105 hrs used at the 40 mA rate. The actual capacity should be determined (not calculated) from capacity testing. It is believed that the capacity in use will be higher than predicted (approximately 130+ hrs).

2. The battery has been used at NSWC for a total of 392 hours in the Mk 16 rig without failure due to battery performance or UBA electronics failure.

3. The shelf/storage life of the battery is listed by the manufacturer as up to 10 years. This is optimistic and should be considered to be 7 years until proven by testing. The manufacturer recommends that the batteries be stored at ambient temperature.

4. The results of the testing at NSWC show the capacity and performance are improved using the lithium battery. There have been no noted problems with the UBA while using the lithium battery.

5. It recommended that the batteries be tested according to MIL-STD-105D at general inspection level II (10% of batteries built) until a lot has zero failures at which time the inspection level should be changed to I (5% sample size). It is also recommended that ten additional samples be set aside for the performance of yearly shelf life tests. Both lot and shelf life tests are recommended to consist of open circuit voltage, closed circuit voltage, capacity discharge testing, and visual inspection.

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Prepared for: CWO4 Randy Palladian, Naval Experimental Diving Unit, Panama City, Florida (In response to Configuration Control Board Concerns)

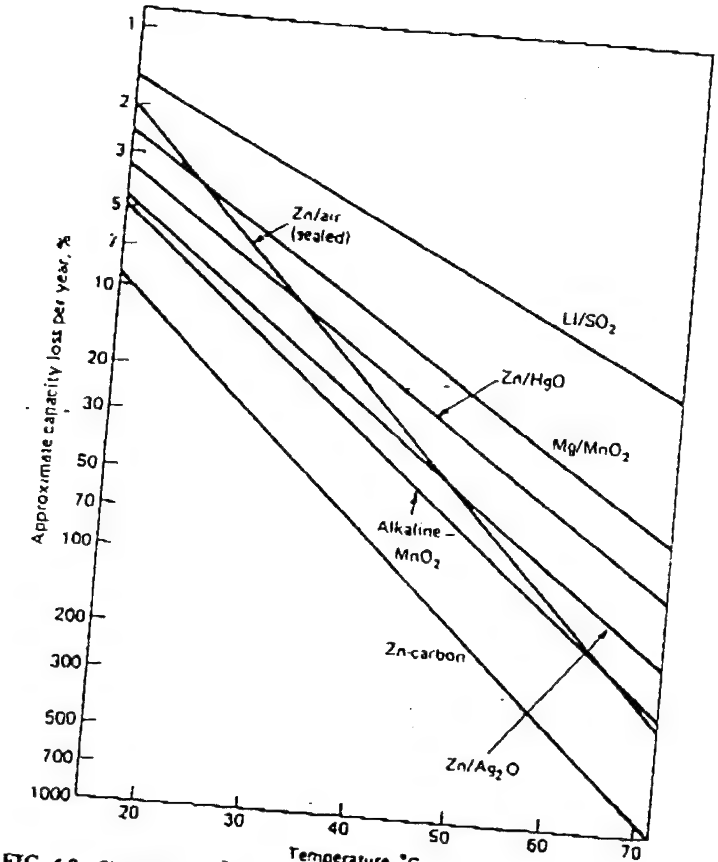

FIG. 4.9 Shelf life characteristics of primary battery systems.

facturer, design, size, discharge conditions, and other factors, they may not apply under specific conditions of use. For these details refer to the appropriate chapter for each battery system.)

4.3.7 Shelf Life of Primary Batteries

The shelf life characteristics of the major primary battery systems are plotted in Fig. 4.9 and show the rate of loss (in terms of percentage capacity loss per year) from 20 to 70°C. The relationship is approximately linear when the log of capacity loss is plotted against the log 1/Temperature (Kelvin). The data assume that the rate of capacity loss remains constant throughout the storage period, which is not necessarily the case with most battery systems. For example, as shown in Part 2 in Figs. 11.16 and 11.47 for several lithium batteries, the rate of loss tapers off as the storage period is extended. The data are also a generalization of the capability of each battery system because of the many variations in battery design and formulation. The discharge conditions and size also have an influence.

CHARGE RETENTION VS STORAGE TEMP.

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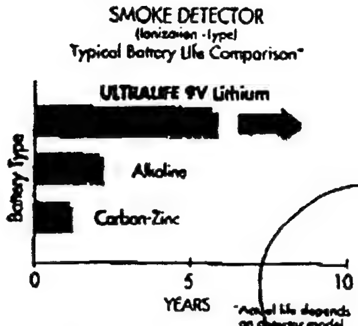
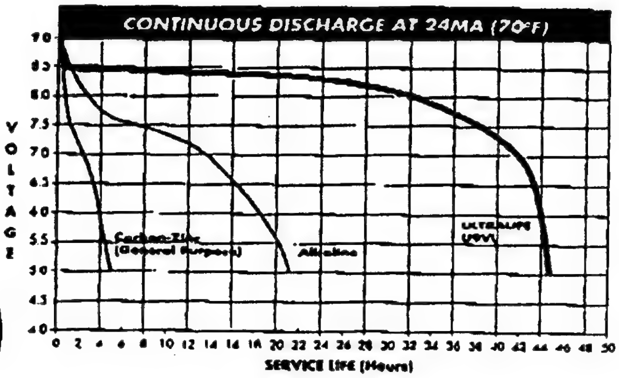


THE ULTIMATE IN LONG LIFE

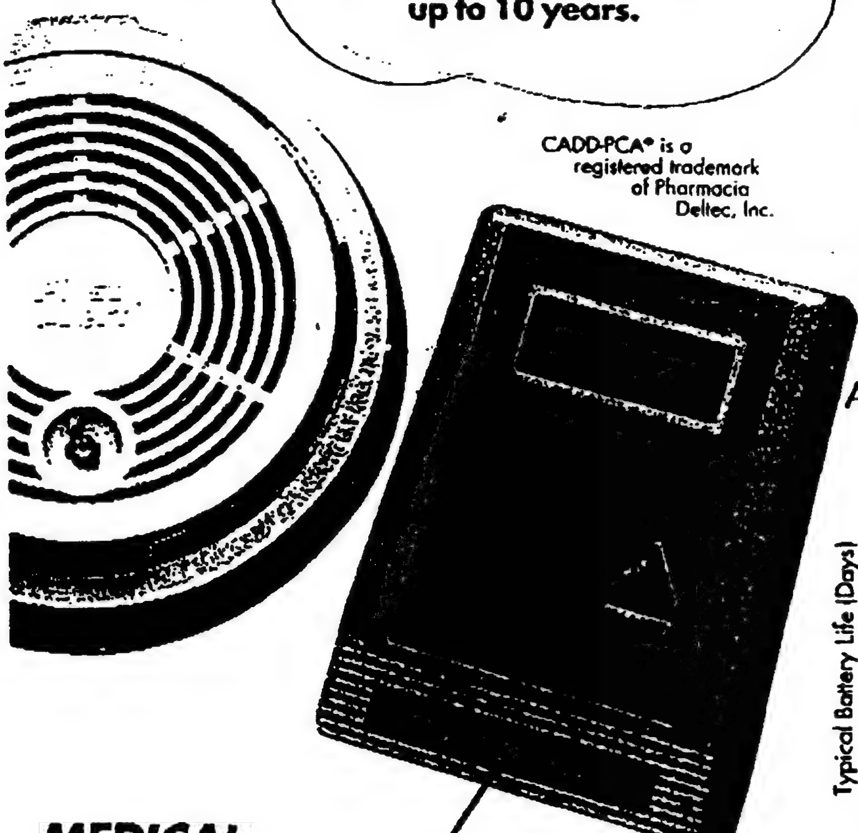
ULTRALIFE 9-Volt Lithium Power Cells have more than twice the capacity and can last **up to four times** as long as premium alkaline batteries in most applications.

In addition, every ULTRALIFE Battery has a shelf life of **up to 10 years.**



THE ULTIMATE IN PERFORMANCE

ULTRALIFE Power Cells have a capacity of 1,200 milliampere-hours. They can supply their energy at a constant voltage over a wide range of discharge conditions.

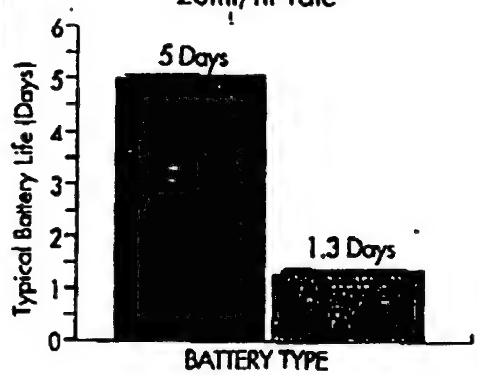


CADD-PCA* is a registered trademark of Pharmacia Deltec, Inc.

AMBULATORY INFUSION PUMP

Typical Battery Life Comparison

20ml/hr rate



MEDICAL

ULTRALIFE Lithium Batteries outperform all other 9-volt batteries and are the ideal power source for critical applications, including ambulatory infusion pumps, telemetry transmitters, and other medical devices where continuous performance is essential.

THE ULTIMATE LOW TEMPERATURE PERFORMER

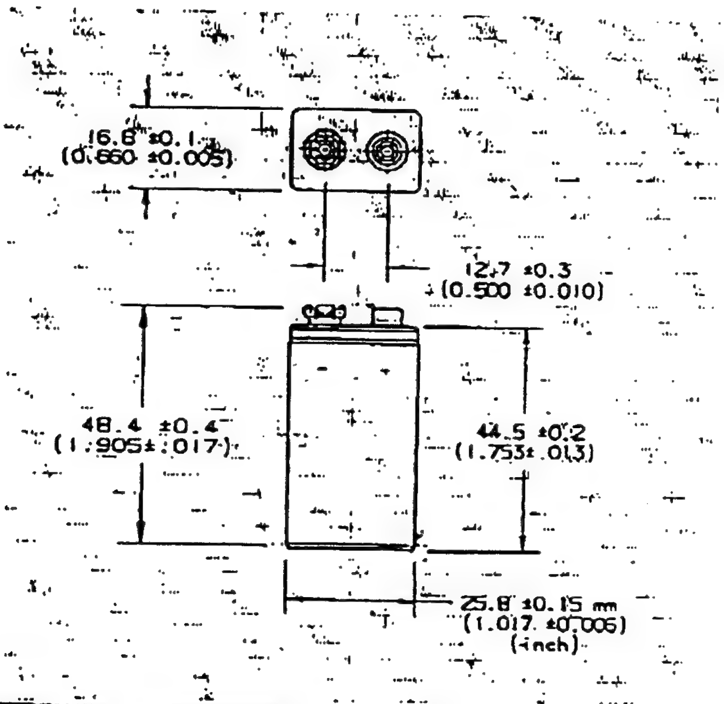
The ULTRALIFE lithium MnO_2 electrochemical system provides superior performance over a wide range of operating temperatures, even down to -40°C, a major consideration for many applications.

CHOOSE ULTRALIFE®—THE ULTIMATE POWER SOURCE

ULTRALIFE®
LITHIUM POWER CELL

U9VL 9V-Size

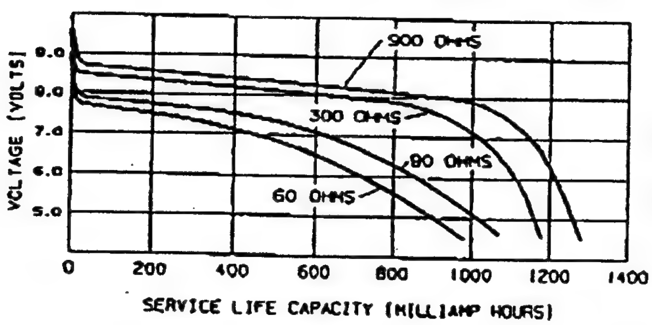
Effective 3 Feb. 93



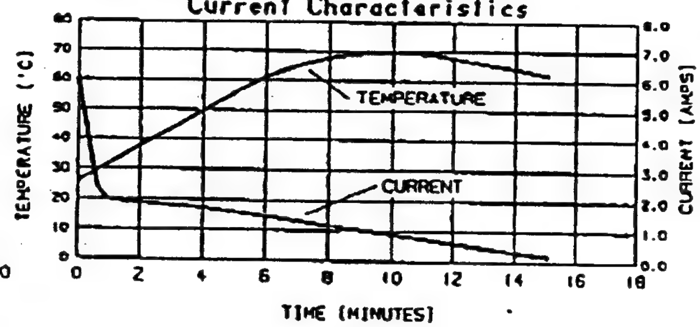
System:	Lithium/Manganese Dioxide, Li/MnO_2
Designation:	NEDA 1604LC
Nominal Voltage:	9.0 Volts
Rated Capacity:	1,200 mAh at 900 Ohms to 5.4 Volts
Maximum Discharge:	120 mA Continuous
Temperature Range:	-40°C to 60°C (-40°F to 140°F)
Weight:	34.4 grams
Volume:	21.40 cm³
Terminals:	Miniature Snap
Jacket:	Plastic Housing/ Label

Recognized under the Component Program of Underwriters Laboratories Inc.

Typical Continuous Discharge Capacity

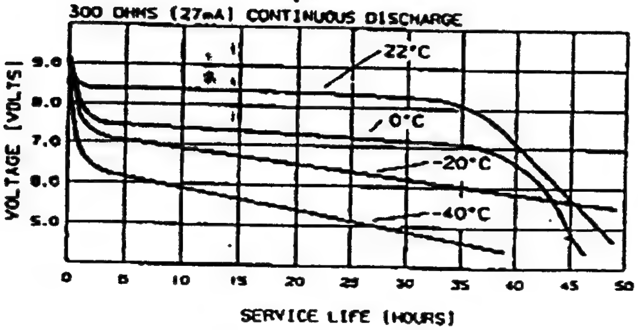


Typical Short Circuit Temperature & Current Characteristics



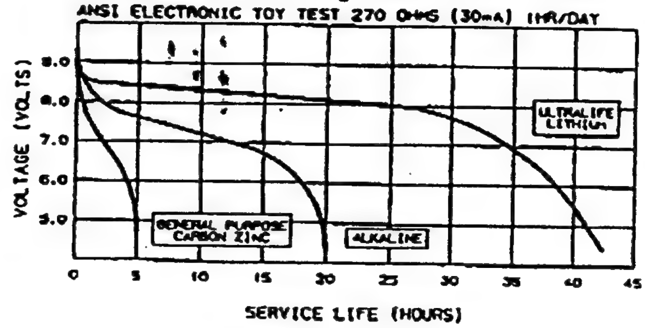
Typical Discharge Characteristics vs Temperature

300 OHMS (27mA) CONTINUOUS DISCHARGE



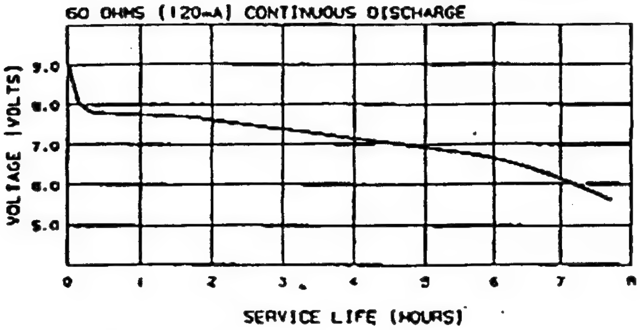
Typical Discharge Characteristics

ANSI ELECTRONIC TOY TEST 270 OHMS (30mA) 1HR/DAY



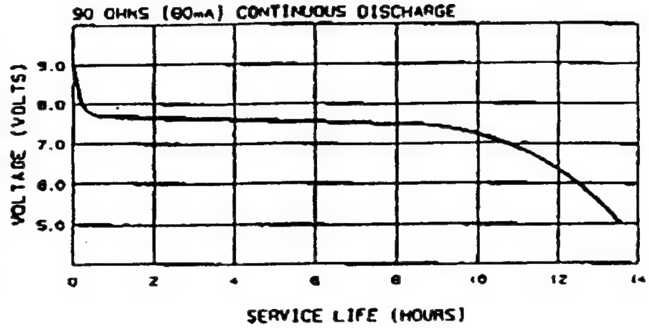
Typical Discharge Characteristics of Fresh Product Stored at Room Temperature

60 OHMS (120mA) CONTINUOUS DISCHARGE



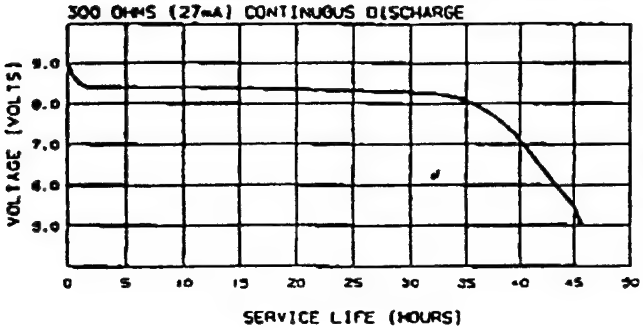
Typical Discharge Characteristics of Fresh Product Stored at Room Temperature

90 OHMS (80mA) CONTINUOUS DISCHARGE



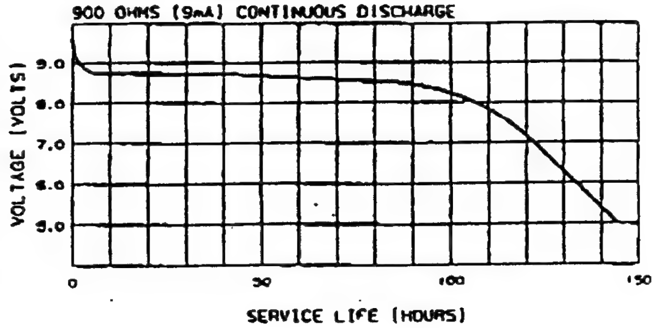
Typical Discharge Characteristics of Fresh Product Stored at Room Temperature

300 OHMS (27mA) CONTINUOUS DISCHARGE



Typical Discharge Characteristics of Fresh Product Stored at Room Temperature

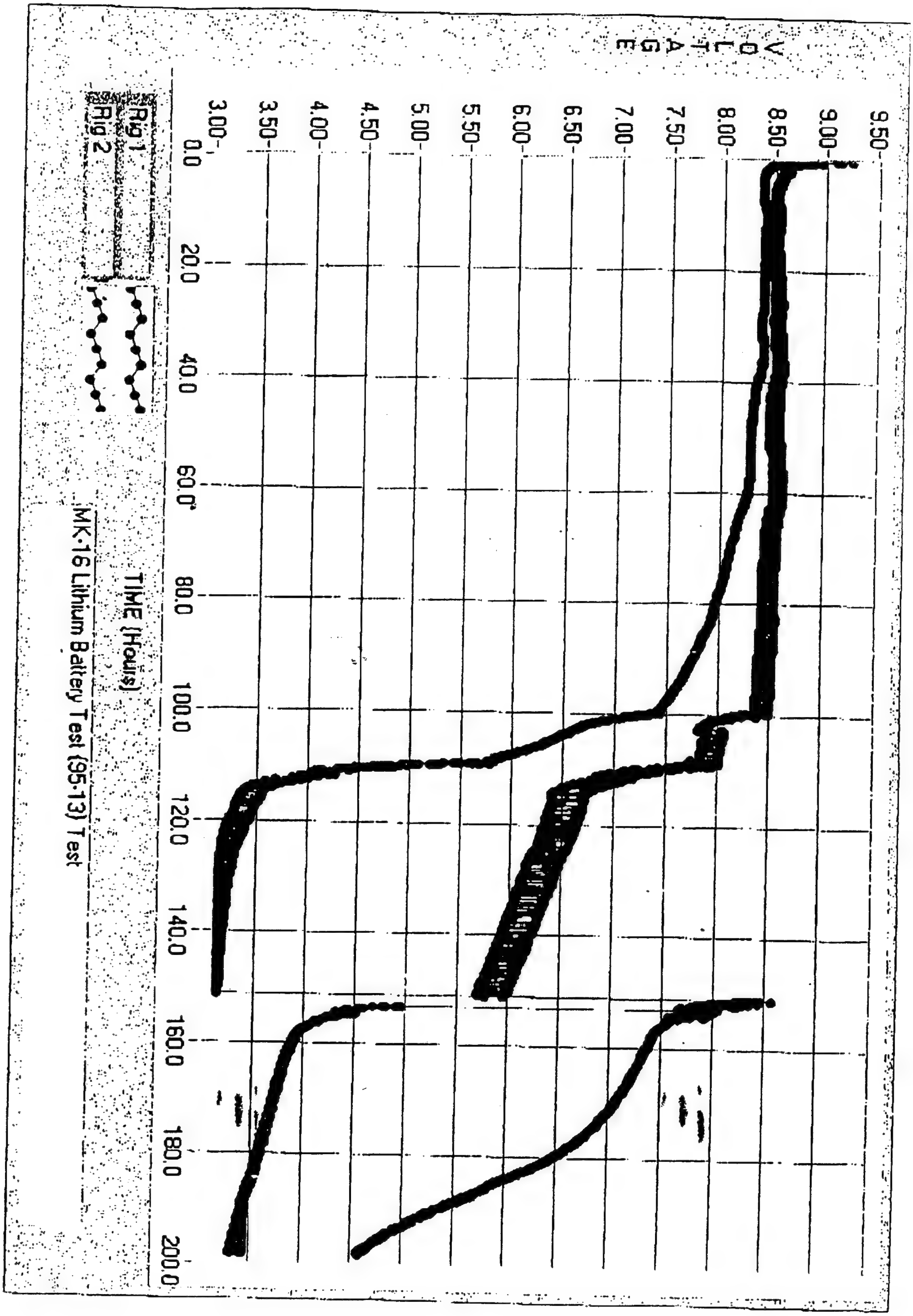
900 OHMS (9mA) CONTINUOUS DISCHARGE

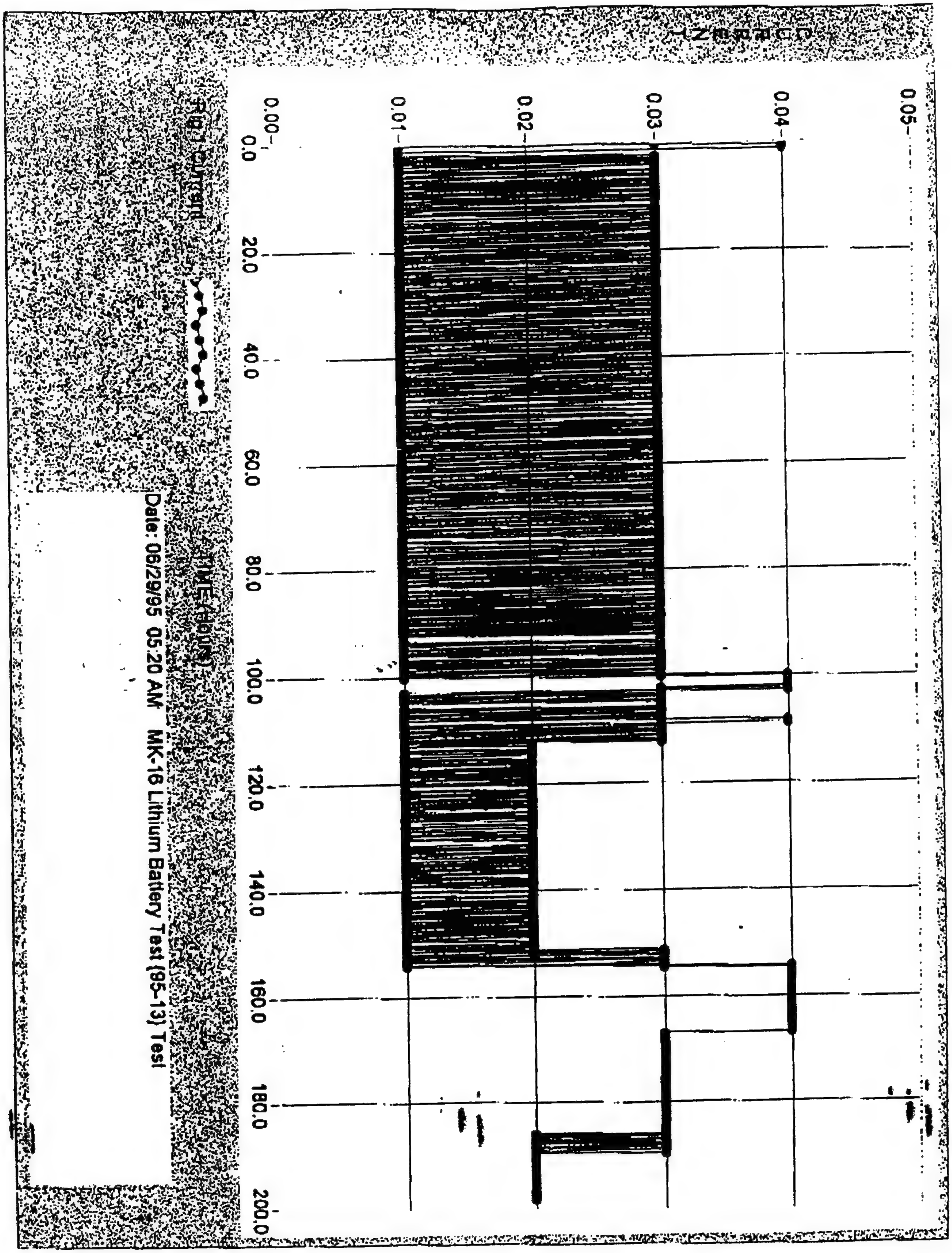


Upon request, ULTRALIFE Batteries, Inc. will provide you with performance curves based on your specific applications.

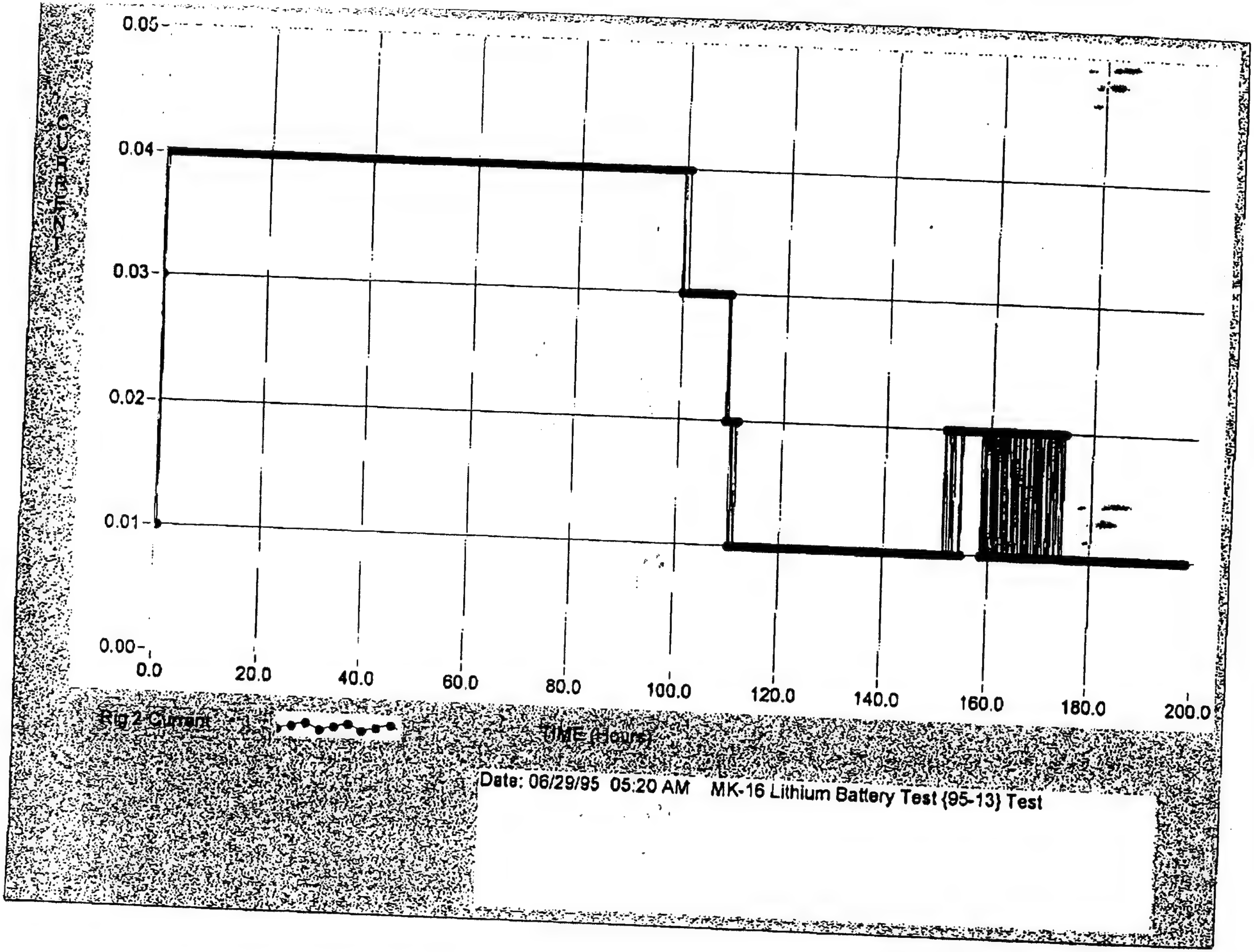
The curves and data in this publication represent product tested under the conditions specified. They do not represent standards or specifications which must be met by ULTRALIFE Batteries, Inc. The company reserves the right to change and improve product characteristics at any time.

For more information, contact
ULTRALIFE Batteries, Inc.
1350 Route 88 South
P.O. Box 622
Newark, NY 14513
Tel: 315-332-7100
FAX: 315-331-7800


VOLTAGE
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
TIME (Hours)
Rig 1
Rig 2
MK-16 Lithium Battery Test (95-13) Test



Rig 1 Current
TIME (Hours)
Date: 06/29/95 05:20 AM MK-16 Lithium Battery Test (95-13) Test
0.00
0.01
0.02
0.03
0.04
0.05
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0


CURRENT
0.05
0.04
0.03
0.02
0.01
0.00
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Rig 2 Current
TIME (Hours)
Date: 06/29/95 05:20 AM MK-16 Lithium Battery Test (95-13) Test

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

1.0 LOT ACCEPTANCE CRITERIA

1.1 SAMPLING SHALL BE IN ACCORDANCE WITH MIL-STD-105D AT A GENERAL INSPECTION LEVEL II SINGLE TYPE SAMPLING PLAN FOR THE INITIAL LOT AND ALL LOTS SUCCEEDING LOTS WITH FAILED SAMPLES.

1.2 SAMPLING SHALL BE IN ACCORDANCE WITH MIL-STD-105D AT A GENERAL INSPECTION LEVEL I SINGLE TYPE SAMPLING PLAN FOR ALL LOTS SUCCEEDING LOTS WITH ZERO FAILURES.

1.3 THE ACCEPTABLE QUALITY LEVEL (AQL) SHALL BE 2.5.

1.4 IF THE RECOMMENDED AQL IS EXCEEDED OR A LOT IS DETERMINED UNSATISFACTORY THE ENTIRE LOT WILL BE SCREENED FOR MATERIAL/WORKMANSHIP DEFECTS AND/OR NEW CELLS SHALL BE PROCURED AND A NEW LOT MANUFACTURED. IN EITHER CASE SAMPLES SHALL BE RESUBMITTED FOR TESTING AND MUST BE DETERMINED TO HAVE THE REQUIRED AQL PRIOR TO ISSUE.

2.0 CELL AND BATTERY TESTING

2.1 EQUIPMENT (ALL EQUIPMENT SHALL HAVE A VALID CALIBRATION STICKER PRIOR TO USE):

2.1.1 DIGITAL VOLTMETER (3 1/2 DIGITS, 0-20 Vdc RANGE)
2.1.2 CONSTANT CURRENT LOAD CAPABLE OF LOADING THE BATTERY AT 40+/-5 mA
2.1.3 TIMER OR COMPUTER DATA ACQUISITION SYSTEM TO MONITOR CAPACITY
2.1.4 CURRENT MONITORING SHUNT TO MONITOR 40+/-5 mA

2.2 PROCEDURE (ALL CELLS AND PRODUCTION BATTERIES):

2.2.1 VISUALLY INSPECT EACH CELL PRIOR TO ASSEMBLY. DISCARD ALL CELLS WITH VISIBLE SWELLING OR LEAKING OR THAT ARE CHARRED, OR DISCOLORED. THIS INSPECTION SHALL NOT CONSTITUTE A FAILURE IN DETERMINATION OF THE AQL. NOTE ALL ANOMALIES IN THE PRODUCTION LOG.

2.2.2 MEASURE THE OPEN CIRCUIT VOLTAGE OF ALL CELLS PRIOR TO ASSEMBLY. DISCARD ALL CELLS WITH AN OPEN CIRCUIT VOLTAGE LESS THAN 3.2 Vdc. THIS TEST SHALL NOT CONSTITUTE A FALURE IN DETERMINATION OF THE AQL. NOTE ALL ANOMALIES IN THE PRODUCTION LOG.

2.2.3 MEASURE THE OPEN CIRCUIT VOLTAGE OF ALL BATTERIES FOLLOWING ASSEMBLY. DISCARD ALL BATTERIES WITH AN OPEN CIRCUIT VOLTAGE LESS THAN 9.2 Vdc. BATTERIES WITH AN OPEN CIRCUIT VOLTGE LESS THAN 9.2Vdc SHALL CONSTITUTE A FAILURE IN DETERMINATION OF THE AQL. NOTE ALL ANOMALIES IN THE PRODUCTION LOG.

2.2.4 VISUALLY INSPECT ALL BATTERIES BUILT FOR LOOSE CONNECTIONS AT THE CELLS INTERCONNECTIONS. INSPECT THE CONNECTOR AND VERIFY THAT IT IS WIRED ACCORDING TO THE DRAWING. INSPECT THE OUTER WRAP FOR PROPER LABELING. NOTE ALL ANOMALIES IN THE PRODUCTION LOG. THIS INSPECTION SHALL NOT BE USED IN THE DETERMINATION OF AQL.

2.2.5 ATTACH EACH BATTERY PRODUCED TO THE CONSTANT CURRENT LOAD SET TO PROVIDE A 40+/-5 mA LOAD AND TO THE CURRENT MONITORING SHUNT. VERIFY THAT THE CURRENT IS 40+/-5 mA. ALLOW THE BATTERY TO DISCHARGE FOR 10 SECONDS AND MEASURE THE VOLTAGE UNDER LOAD. ANY BATTERY WHICH HAS A VOLTAGE UNDER LOAD OF LESS THAN 9.0 Vdc SHALL CONSTITUTE A FAILURE IN THE DETERMINATION OF THE AQL. NOTE ALL ANOMALIES IN THE PRODUCTION LOG.

2.3 PROCEDURE (RANDOM SAMPLES ACCORDING TO MIL-STD-105D BASED ON LOT SIZE)

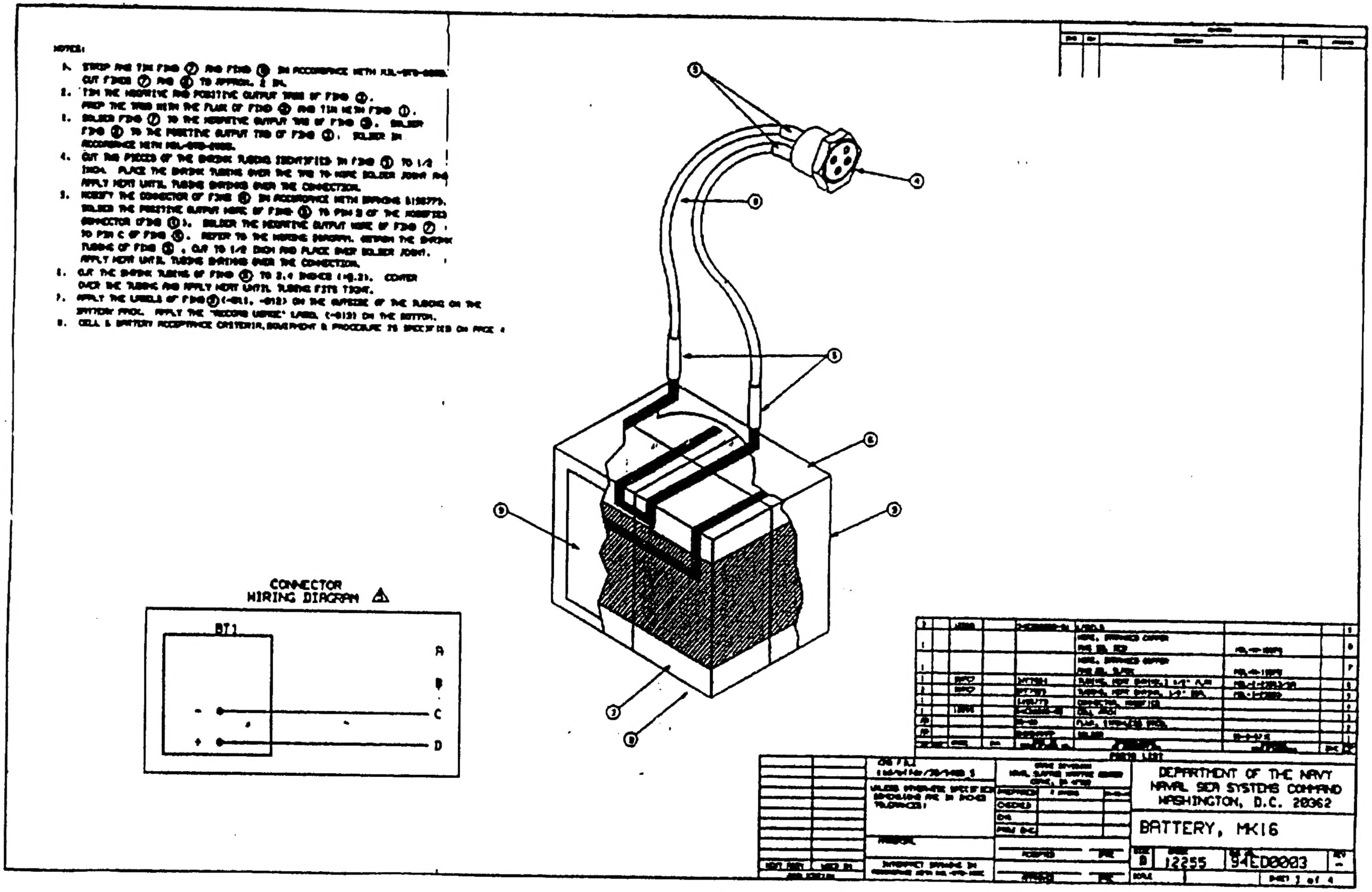
2.3.1 MEASURE THE CAPACITY BY ATTACHING EACH OF THE RANDOMLY CHOSEN SAMPLES TO THE LOAD CIRCUIT UNDER A 40mA LOAD. MONITOR THE CURRENT AND VOLTAGE. DISCHARGE EACH BATTERY TO A VOLTAGE OF 4.2 Vdc AND CALCULATE THE CAPACITY. ANY BATTERY WHICH DOES NOT HAVE A MINIMUM OF 5.0 Ah CAPACITY IS CONSIDERED A FAILURE AND IS PERTINENT WHEN CALCULATING THE AQL. NOTE ALL ANOMALIES IN THE PRODUCTION LOG.

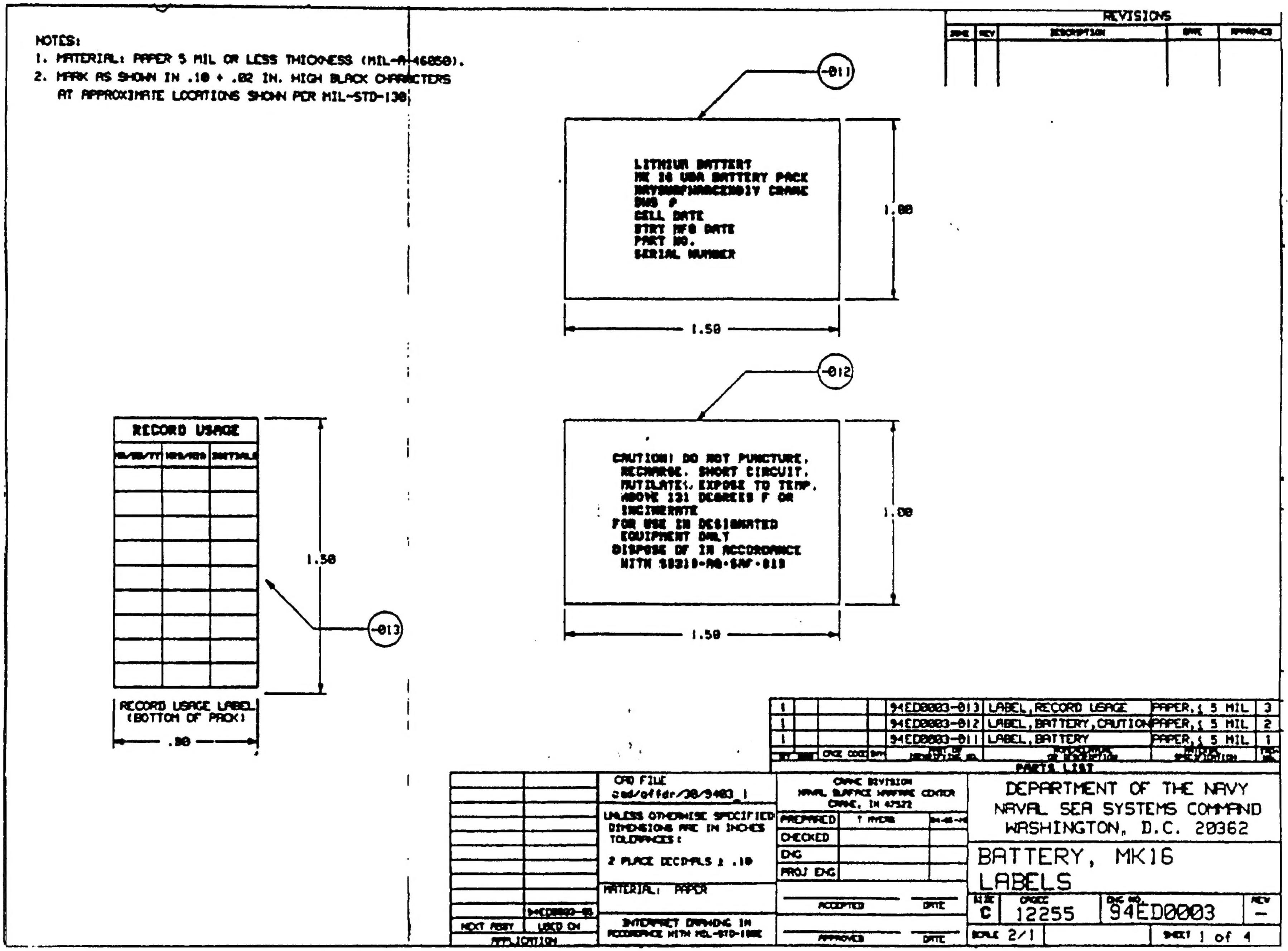
2.3.2 SET ASIDE 10 SAMPLES FROM EACH LOT. MARK THE DATE AND THE LOT NUMBER ON EACH CELL. THESE CELLS SHALL BE USED TO VERIFY SHELF/STORAGE LIFE. ONE CELL SHALL BE DISCHARGED EACH YEAR AS IN 2.4.1 ABOVE. THIS INFORMATION SHALL NOT CONSTITUTE A FAILURE IN THE DETERMINATION OF THE AQL.

2.4 TEMPERATURE REQUIREMENTS:

2.4.1 STORAGE: NOT TO EXCEED 85 F.
2.4.2 DISCHARGE AND MEASUREMENT 59 - 85 F.

NEXT ASSY	USED ON	CAD FILE sad/offdr/30/3480_4	CRANE DIVISION NAVAL SURFACE WARFARE CENTER CRANE, IN 47522	DEPARTMENT OF THE NAVY NAVAL SEA SYSTEMS COMMAND WASHINGTON, D.C. 20362
APPLICATION		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES:	PREPARED T MYERS	BATTERY, MK16 CELL PACK
			CHECKED	
			ENG	
			PROJ ENG	
		MATERIAL PAPER, ADHESIVE BACKED	ACCEPTED DATE	SIZE C · CAGEC 12255 · DWG NO. 94ED0003 · REV -
		INTERPRET DRAWING IN ACCORDANCE WITH MIL-STD-100E	APPROVED DATE	SCALE · SHEET 4 of 4

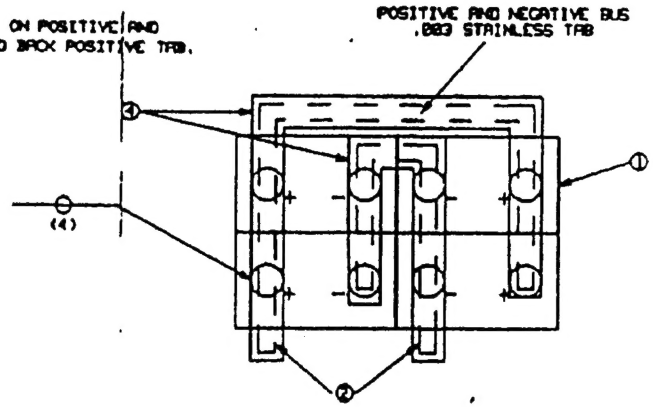

CONNECTOR WIRING DIAGRAM
BT1
A
B
C
D
PARTS LIST
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362
BATTERY, MK16
12255
94ED0003

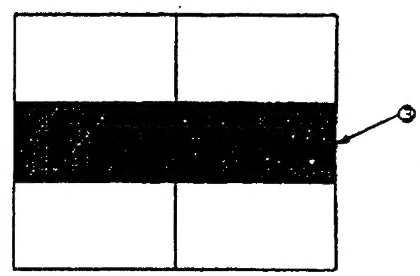

NOTES:
1. MATERIAL: PAPER 5 MIL OR LESS THICKNESS (MIL-A-46050).
2. MARK AS SHOWN IN .10 + .02 IN. HIGH BLACK CHARACTERS AT APPROXIMATE LOCATIONS SHOWN PER MIL-STD-130
REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
-011
LITHIUM BATTERY
MK 16 UBA BATTERY PACK
SERIAL NUMBER
CELL DATE
PART NO.
1.00
1.50
-012
CAUTION! DO NOT PUNCTURE,
RECHARGE, SHORT CIRCUIT,
FOR USE IN DESIGNATED
EQUIPMENT ONLY
DISPOSE OF IN ACCORDANCE
1.00
1.50
RECORD USAGE
1.50
-013
RECORD USAGE LABEL
(BOTTOM OF PACK)
.80
94ED0003-013
LABEL, RECORD USAGE
PAPER, ≤ 5 MIL
94ED0003-012
LABEL, BATTERY, CAUTION
PAPER, ≤ 5 MIL
94ED0003-011
LABEL, BATTERY
PAPER, ≤ 5 MIL
PARTS LIST
CAD FILE
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
2 PLACE DECIMALS ± .10
MATERIAL: PAPER
INTERPRET DRAWING IN ACCORDANCE WITH MIL-STD-100E
NEXT ASSY
USED ON
APPLICATION
CRANE DIVISION
NAVAL SURFACE WARFARE CENTER
CRANE, IN 47522
PREPARED
CHECKED
ENG
PROJ ENG
ACCEPTED
DATE
APPROVED
DATE
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362
BATTERY, MK16
LABELS
SIZE
C
CAGE
12255
DWG NO.
94ED0003
REV
—
SCALE 2/1
SHEET 1 of 4

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

NOTES:

1. CONFIGURE THE CELLS OF FIND ① SHOWN. USE THE TAPE OF FIND ③ TO SECURE THE CELLS IN THE DESIRED CONFIGURATION.
2. SPOT WELD THE TAB MATERIAL OF FIND ② TO THE BATTERY TABS IN ACCORDANCE WITH MIL-W-6858. USE THREE OR FOUR NUGGETS PER WELD.
3. PLACE ELECTRICAL TAPE OF FIND ④ ON POSITIVE AND NEGATIVE TABS FOR ISOLATION. BEND BACK POSITIVE TAB.





QTY REQD		CAGE CODE		PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO.
AR					TAPE, ELECTRICAL		4
1				A-A-1687	TAPE, PRESSURE SENSITIVE,1/2"XS"		3
2				TYPE 316	STAINLESS STEEL ANNEALED, .109 X .003		2
4		OLU59		U9VL	CELL, Li/MnO_2, 9V NOMINAL, NON-MAG.		1

PARTS LIST

CAD FILE	c:d/offdr/30/9403_4
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES:	
MATERIAL	PAPER, ADHESIVE BACKED
INTERPRET DRAWING IN ACCORDANCE WITH MIL-STD-100C	
NEXT ASSY	USED ON
APPLICATION	

CRANE DIVISION
NAVAL SURFACE WARFARE CENTER
CRANE, IN 47522

PREPARED	T HYDRE	
CHECKED		
ENG		
PROJ ENG		
ACCEPTED		DATE
APPROVED		DATE

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362

BATTERY, MK16
CELL PACK

SIZE	CAGE	DWG NO.	REV
C	12255	94ED0003	—
SCALE 2/1		SHEET 2 of 4	